

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
18 November 2004 (18.11.2004)

PCT

(10) International Publication Number  
**WO 2004/098916 A1**

- (51) International Patent Classification<sup>7</sup>: **B60G 17/01**
- (21) International Application Number:  
PCT/US2003/025267
- (22) International Filing Date: 11 August 2003 (11.08.2003)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:  
10/428,274 2 May 2003 (02.05.2003) US
- (81) Designated States (national): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.
- (84) Designated States (regional): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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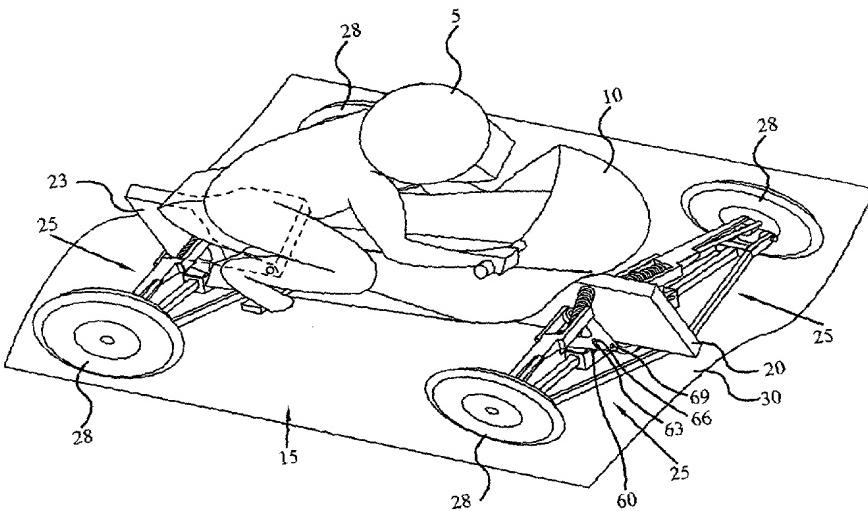
Published:

— with international search report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

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(54) Title: VEHICLE LEAN AND ALIGNMENT CONTROL SYSTEM



(57) Abstract: A frame and suspension for a vehicle provides automatic lean and alignment. The lean is determined by force sensors, the speed and/or the angle of turn and is provided by actuators in the suspension in accordance with a predetermined protocol in an electronic control unit (ECU). The protocol also provides shock absorption by rapidly tracking a contour of a surface on which the vehicle rides. The suspension is provided by a plurality of arm assemblies each including a lower arm, an upper control arm, and an actuator motivily connected to the lower arm and to the upper control arm. The arm assemblies are pivotally connected to the frame on a common axis. The arm assemblies generally form parallelograms and are actuated in concert to remain generally parallel to each other through a range of angles to adjust the lean of the vehicle. The arm assemblies are also actuated independently of each other to accommodate variations in the contour. In one aspect, an actuator controlled by an ECU can be replaced by a mechanical actuator that can be activated manually such as by a driver's own leaning weight.

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**VEHICLE LEAN AND ALIGNMENT CONTROL SYSTEM****BACKGROUND OF THE INVENTION**1. Technical Field

This invention generally relates to vehicles that are capable of being leaned and that have rear steering capabilities, and more specifically to a frame and suspension system that facilitates leaning and rear steering on a vehicle having more than two wheels.

2. Background Art

Vehicles capable of leaning include motorcycles. Of course, standard configuration motorcycles have only two wheels so that leaning the vehicle happens naturally. The benefits of leaning include that leaning facilitates turning. Leaning the motorcycle in a direction while the motorcycle is moving forward actually pulls the front steering in the same direction. Another benefit of leaning the motorcycle is that the wheels are also leaned and better support the forces applied to the wheel and tire. At the same time, leaning increases the contact area of the tire on a driving surface. Still further, leaning the motorcycle better positions the center of gravity on the line of force applied to the surface by the motorcycle and driver.

Rear wheel alignment by a rear steering mechanism has been implemented on vehicles having four wheels, such as automobiles. Rear steering mechanisms have been provided for counter steering the rear wheels for greater maneuverability. These counter steering mechanisms are generally restricted to operation at low speeds.

## DISCLOSURE OF THE INVENTION

The present invention relates to a vehicle that includes many of the advantages of a motorcycle on a vehicle having three or more wheels. With the frame and suspensions of the present invention, the same advantages of leaning the wheels and the frame of the vehicle supported on the frame are provided.

With each additional wheel over two, an additional adhesion point is provided. Thus, a vehicle with four wheels will have twice as many adhesion points as a standard motorcycle. As such, the vehicle will enable faster stopping. Also, the vehicle can automatically lower the frame and provide a lower center of gravity of the vehicle during deceleration. One way of carrying this out is to automatically cause the rear suspension to mirror the front suspension during braking.

Furthermore, it is contemplated that approximately a thirty percent increase in speed around corners may be achieved with the present invention. This is due, in part, to the increased adhesion patch at each of the adhesion points when the wheels are leaned during turning. Still further, with the frame leaning into turns, the centrifugal and gravitational forces are more evenly distributed among the adhesion points. The vehicle can include additional advantages of automatically leaning the frame and wheels and aligning the rear wheels. Aligning the rear wheels reduces drag that typically occurs during turns, and thus improves gas mileage or efficiency in general.

Another advantage provided by the frame and suspension of the present invention is that they include shock absorption by way of shock absorbers and an electro-mechanical tracking mechanism. The term "shock absorbers" as used throughout this disclosure can include a spring coiled over a shock absorption device, a torsion bar, or an air shock for example. In any case, it is to be understood that "shock absorber" as used herein refers to a mechanism having support characteristics capable of supporting the chassis and body weight of a vehicle and having shock absorbing characteristics. The shock absorption of the frame and suspension can be in addition to shock absorbers on a vehicle body, such as on a motorcycle body. That is, the motorcycle body with its front and rear

shocks can be supported on the frame and suspension of the present invention. As can be appreciated this offers redundancy and provides an exceedingly smooth ride. The stiffness of the various shock absorbers and tracking mechanism can be varied to absorb a variety of shock and vibrations.

5           The shock absorbers of the frame and suspension system of the present invention are mounted as close to a central longitudinal axis as possible. This location together with the structural relationship of the shock absorbers to the frame and suspension provides the advantage of increased mechanical advantage for forces applied to the wheels, the frame, vehicle body, and the driver/rider(s)

10           with increased lean.

15           The change in position of the shock absorber(s) relative to the lower arm helps reduce the transfer of force to the other side of the frame. Furthermore, the present suspension includes an arm assembly for each wheel that it supports. Each arm assembly can be deflected independently so that the load is minimally transferred to the other side of the frame.

20           The lean can be effectuated automatically with an electronic control unit (ECU). This enables the system to automatically select the amount of lean based on the speed and angle of turn of the vehicle. Alternatively or additionally, the angle of lean can be determined and automatically adjusted based on feedback from one or more force sensors that are positioned to detect a distribution of gravitational and centrifugal forces. Likewise, the angle of turn of the rear wheels can be automatically adjusted by the ECU. Thus cornering can be significantly aided and the protocol in the ECU can be configured and/or adjusted to place these automatic features at their maximum with a selected safety factor.

25           Alternatively, the ECU can be replaced by other processors including mechanical processors. Such mechanical processors could employ a variety of springs including air springs, and could include compressible and non-compressible fluids to coordinate movement between arm assemblies. Further alternatively, the lean could be effected through a set of gears or a force multiplying device such as a

fluid piston, rack and pinion mechanism. Still further, part of the system could be automatic and the rest of the system could be manually controlled by the vehicle driver. In this case, the driver replaces the portion of the processor that would otherwise automatically control at least some of the function of the frame and suspension system. For example, the frame and suspension system could be configured to automatically track a contour of the driving surface for improved shock absorption, while requiring the driver to determine the amount of lean by shifting his or her body weight, as with a standard motorcycle. In this case, the frame and suspension could normally hold the vehicle in an upright position when no substantial leaning force is applied, and lean can depend on the sensory perception and control of the driver.

In an exemplary basic form, a vehicle with a lean and alignment control system in accordance with the present invention includes a frame having a central longitudinal axis. The frame also has an upright axis that is adapted to be generally perpendicular to a surface on which the vehicle rests when the frame is in a neutral position with no net leaning loads applied. A vehicle body is supported on the frame. A suspension comprising a plurality of arm assemblies is connected to the frame. Each arm assembly includes a lower arm having an inboard end and an outboard end, an upper control arm having an inboard end and an outboard end, and an actuator mounted to the lower arm and motively connected to the upper control arm. Many variations are possible without departing from the spirit and scope of the invention. Some of these variations will become apparent in the detailed description below. It is to be understood that while many aspects of the invention are described herein with regard to a vehicle, the invention also encompasses the frame and suspension system by itself. Likewise, the invention encompasses the suspension system and the individual arm assemblies that make up the suspension.

The present invention in one aspect includes a method of properly leaning and aligning a vehicle supported on a suspension. This method has several basic steps including automatically leaning a frame of the vehicle at a predetermined

angle relative to an arm of one of a plurality of arms assemblies. Automatically leaning the frame can further include providing a protocol in a processor to control the lean. Data is then automatically fed from a vehicle speed sensor and a steering position sensor to the processor. The frame is automatically moved relative to the  
5 arm according to the protocol under processor control.

In another aspect, the present invention includes a method of tracking a contour of a driving surface to absorb shock. The method includes automatically and independently raising and lowering a plurality of arms of a vehicle suspension to accommodate variations in the contour. In order to do this, the system provides  
10 feed forward by a mechanical shock absorber. Then the step of raising and lowering the plurality of arms is accomplished by providing feedback to a processor; which raises and lowers the arms under processor control.

The foregoing and other features and advantages of the present invention will be apparent from the following more detailed description of the particular  
15 embodiments of the invention, as illustrated in the accompanying drawings.

**BRIEF DESCRIPTION OF THE DRAWINGS**

FIG. 1A is a perspective view of a vehicle incorporating frames and suspensions according to an embodiment of the present invention;

5 FIG. 1B is a diagrammatic end view of the frame and suspension of Figure 1 showing a variety of lean positions of the frame and wheels;

FIG. 2A is a perspective view of a frame and suspension showing the frame in a leaned position;

FIG. 2B is a perspective view of a portion of an underside of the frame and suspension in a region indicated by arrow 2B in Figure 2A;

10 FIG. 3A is a perspective view of an arm assembly of the suspension according to the embodiments of Figures 1-2 above;

FIG. 3B is an exploded perspective view of the arm assembly of Figure 3A;

15 FIG. 4A is a side sectional view of the actuator housing taken along lines 4A-4A of Figure 3A;

FIG. 4B is a perspective view depicting an alternative actuator drive;

FIG. 4C is a partial schematic view of the actuator drive of Figure 3C showing a connection to a fluid transfer device;

20 FIG. 4D is a partial end view showing the connection of the fluid transfer device of Figure 3D to a frame and suspension of the present invention;

FIG. 4E is a sectional view of an outboard position sensor taken along lines 4E-4E of Figure 4A;

FIG. 5 is a sectional view of a hub assembly taken along lines 5-5 of Figure 3A;

5 FIG. 6 is a top view of a frame and suspensions of the present invention, with the frame incorporated as a rear swing arm of a motorcycle;

FIG. 7 is a perspective view of the rear steering mechanism according to the present invention; and

10 FIG. 8 is a block diagram depicting sensors, a actuator motors, speed controllers, and an ECU that may be used in accordance with any of the embodiments of the present invention.

**DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION**

As discussed above, embodiments of the present invention relate to a vehicle, and a frame and a suspension system for the vehicle.

As shown in Figure 1A, a driver 5 is seated on a vehicle 10 that is supported on a frame and suspension system 15 in accordance with the present invention. In the example of Figure 1, the frame and suspension system includes a front frame 20 and a swing arm frame 23. Each of frames 20 and 23 has separate suspensions in the form of arm assemblies 25. Each arm assembly 25 is independently and pivotally connected to the frames 20, 23. The arm assemblies 25 support wheels 28 at outboard ends. The wheels 28, of course, support the frame and suspension system 15 and the vehicle 10 on a driving surface 30.

As can be appreciated from the diagrammatic end view of Figure 1B, the arm assemblies 25 permit the frames 20, 23 to lean through a range of angles relative to a plane 31 that is upright and substantially perpendicular to a plane 32 defined by the arm assemblies in a neutral position with no net leaning forces thereon. The arm assemblies 25 have structural details to be further described below that generally form parallelograms and thereby lean the wheels 28 generally at the same angle to the arm assembly plane 32 as the frame 20, 23 is to the arm assembly plane 32. This is the case, at least, when the surface 30 is reasonably smooth so as not to raise or lower any of the arm assemblies out of the plane 32. Thus, it can be seen that in cornering applications, the wheels 28 and the frames 20, 23 will be substantially parallel to each other. The frames 20, 23 will generally shift a center of gravity to better balance the centrifugal forces. Both the wheels 28 and the frames 20, 23 will be oriented to provide a stronger support for the centrifugal and gravitational forces that will be applied.

Figure 2A is a perspective view of a frame and suspension system 33 with a frame 34 similar to frame 20, but having a length sufficient to support a whole vehicle. This particular configuration lends itself to supporting a bicycle, such as

a recumbent bicycle. However, combination with any vehicle, motorized or not, whether existing or not yet designed, is within the spirit and scope of the invention. Likewise, frames of any configuration can be substituted for the frames 20, 23, and 34 as long as the substituted frames provide similar mountings to the exemplary embodiments described herein. Figure 2 shows the frame 34 leaned to one side. That is, the frame 34 is leaned toward at least one arm assembly 25 and away from the other arm assembly 25 on an opposite side of the frame 34.

In the position shown in Figure 2A, a parallelogram effect becomes apparent. That is, each arm assembly 25 has a lower arm 35, an upper control arm 36, an actuator 39 connecting inboard ends of the lower arm 35 and the upper control arm 36, and a hub assembly 42 connecting the outboard ends of the lower arm 35 and the upper control arm 36. Each of the lower arm 35, upper control arm 36, actuator 39, and hub assembly 42 are pivotally connected to each other. All of the arm assemblies 25 are pivotally connected to the frame 34 on a common pivot axis 45. In this way a height mismatch in points of connection is avoided when the frame 34 is leaned. However, it is possible to mount the arm assemblies on laterally outward edges of a wider frame without departing from the scope of the invention. The arm assemblies are also connected to the frame 34 by shock absorbers 48. The shock absorbers permit damped movement as will be described in further detail below.

Figure 2B is a perspective view of an underside of the frame 20 in a region indicated by arrow 2B in Figure 2A. Figure 2B shows a connection of the lower arm 35 by way of a lower arm pin 49 that is press fit or otherwise fixed to the lower arm 35. The lower arm pin 49 rotatably moves in a bore in the frame 20. An inboard position sensor 50 is fixed to the frame 20 in alignment with the pin 49 to sense a rotational position of the lower arm relative to the frame 20. The position sensor 50 can be provided as a potentiometer similar to those to be described below with regard to outboard position sensors.

Figure 3A shows one of the arm assemblies 25 in a perspective view. The actuator includes a motor 51 mounted to the lower arm 35. The motor 51 is motively connected to an actuator arm 54 through an actuator housing 57. The actuator arm 54 is pivotally mounted on the housing 57 at a first connection 69.

5 The actuator housing 57 has a drive slot 60 in which a cam pin 63 is caused to move by the motor 51. The cam pin 63 also extends into a cam slot 66 in the actuator arm 54. As can be appreciated, moving the cam pin 63 along a length of the drive slot also forces or cams the actuation arm to move through a predetermined range of motion. Movement of the actuation arm causes the upper 10 control arm 36 that is pivotally connected to the actuation arm at a second connection 72 to move. The portion of the actuator arm 54 between the first connection and the second connection generally provides one side of a parallelogram formed by the arm assembly 25. A generally parallel opposite side is provided by the hub assembly 42. It is to be noted that the actuator arm can be 15 one of a pair of actuator arms 54 that straddle the actuator housing for added strength and durability.

The shock absorber 48 is connected to the actuator arm 54 at a third connection 75 that is disposed at an angle from the second connection relative to the first connection 69. The angle is defined as the angle between respective lines 20 through the first and second connections and through the first and third connections. This angle can be in the range from zero to ninety degrees. Specifically, this angle is normally selected to be approximately forty-five degrees. The third connection 75 is located outboard of the second connection 72. That is, when the arm assembly is on a vehicle, the third connection 75 will be 25 located farther from the frame than the second connection. Referring back to Figure 2 it can be seen that the third connection 75 is located above the upper control arm 36 at one end of the range of motion. The third connection 75 is below the upper control arm 36 at the other end of the range of motion. Thus, the shock absorber 48 has an end to end position that is generally horizontal or 30 parallel to a respective upper control arm 36 at one end of the range of motion. The shock absorber reaches a position that is at approximately forty-five degrees

relative to planes defined by the upper control arm 36 and the lower arm 35 at the other end of the range of motion.

As can be appreciated, the present invention is configured to substantially balance centripetal forces, gravitational forces, and shock forces between arm assemblies 5 on opposite sides of the frame.

The overall relationship between the shock absorbers 48, upper control arms 36, lower arms 35, and the actuator arms 54 is such that a mechanical advantage is maintained generally the same throughout the range of motion of the arm assemblies 25. For example, this is due in part to the connection 75 of the shock absorber 48 to the actuator arm 54 rising from a position nearly on the same plane as the lower arm 35 to a position above the upper control arm 36. This added height to the shock absorber connection provides a lever arm for horizontal forces applied through the upper control arm 36. On the other hand, the reorientation of the shock absorber on the other side of the frame to a generally forty-five degree angle better positions the shock absorber 48 to receive the additive forces that are typical for lean in that direction. In other words, the system is constantly reorienting the shock absorbers, upper control arms, actuator arms and frame to enable the shock absorbers to efficiently handle the forces applied to the arm assemblies 25. Hence, the system maintains a balance and a mechanical advantage for the shock absorbers to effectively receive the forces applied to the suspension system throughout the range of motion of each of the arm assemblies 25.

It follows that by the placement of the actuator arms 54 relative to the frame 20, 23, 34, upper control arms 36, lower arms 35, and relative to the shock absorbers 48, a mechanical advantage is achieved and maintained for both sides of the vehicle 10. Furthermore, the shock absorbers 48 are better able to handle forces as the lean of the frame 20, 23, 34 and vehicle 10 increases. This is important because the remaining range of motion of the arm assemblies 25 in their leaned positions is limited and additional shock may need to be absorbed by the

shock absorbers 48. On the other hand, much of the shock can be absorbed by a tracking function effectuated by moving the arm assemblies 25 by the actuators 39 as will be described in greater detail below.

Figure 3B is an exploded perspective view of the arm assembly 25 showing additional details. For example, the actuator housing 57 has a lead screw cover 78 enclosing the lead screw 81 and its associated components. A ball nut 84 is received on the lead screw 81 and moves along a length of the lead screw 81 as the motor 51 is run. The cam pin 63 is provided by oppositely extending shafts 85 that are rigidly connected to the ball nut 84 and extend outwardly from the ball nut 84 in order to engage in the drive slot 60 and the cam slot 66. Typically the ball nut 84 and the cam pin 63 are one integral piece.

The hub assembly includes a pair of hub bearings 90 for rotatably supporting an axle in known configurations. The axle may include a plurality of universal or constant velocity joints. The hub assembly 42 also includes a hub pin 93 that is to be press fit or otherwise fixed to a lower end of the hub assembly 42. The hub pin 93 is rotationally supported on an outboard end of the lower arm 35 as will be described in greater detail below.

Figure 4A is a sectional view of the actuator housing 57 taken along lines 4-4 of Figure 3A. The lead screw 81 and ball nut 84 are received in a lead screw opening 94. The lead screw opening 94 can be provided by boring the housing 57. A thrust bearing 95 is disposed at a lower end of the opening 94 for receiving a lower end of the lead screw 81. The lead screw 81 has a lead screw gear 96 for receiving a driving force, a bushing 99, and a thrust bearing 102 supported thereon. The lead screw 81 and its associated components are enclosed by the lead screw cover 78. This can be accomplished by providing a threaded connection 105 between the cover 78 and the housing 57. A seal may also be provided between the cover 78 and the housing 57.

The motor 51 is mounted on the housing 57 such as by screws as indicated at 108. Mounted thus, a motor drive shaft 111 extends into the housing 57. A drive gear 112 drives an idler gear 114, which drives the lead screw gear 96. The drive gear 112 and the idler gear 114 are received into a gear train opening 117.

5       The gear train opening 117 is closed by a gear train cover 118 which can be attached to the housing 57 by screws or the like. A seal may be placed between the gear train cover 118 and the housing 57. Furthermore, a seal in the form of telescoping plates or a resilient material may be provided to close the slot 60 shown in Figures 3A and 3B. Such a seal is designed to accommodate the movement of the cam pin 63 in the drive slot 60, (shown in Figures 3A and 3B), while substantially sealing an interior of the housing 57. With further reference to Figure 4A, at least one through bore 120 may be formed as an extension from a screw hole for screws at 108 into the lead screw opening 94. The through bore 120 thus provides a flow path for an oil bath 123 that circulates about and cools the lead screw 81 and its components. It is to be understood that the motor and lead screw may be rotated exceedingly fast. Hence, the oil bath 123 is usually needed to prevent overheating and failure of the components. It is to be further understood that the lead screw can be replaced by a worm gear that would provide even faster actuation or permit fast actuation at lower revolutions per minute of the motor. However, the surface area of engagement between the worm gear and splines that the worm gear motivily engages is very small. Hence, the strength of the actuator will be greatly reduced. Further alternatively, the motor could have an integral lead screw and could be mounted substantially in the location of the lead screw cover 78.

25       The actuator includes the motor 51, the actuator housing 57 with its contents, and at least part of the actuator arms 54. Alternatively, the actuator 39 could be replaced by a linear actuator that is pivotally mounted to the lower arm 35 or the upper control arm 36 and pivotally mounted to the actuator arm. However, it is to be understood that the actuator mechanism inhibits back driving 30 of the mechanism by forces applied through the shock absorber 48.

Figures 4B-4D show an alternative actuator drive mechanism 141 that can be substituted for motor 51. The drive can include a drive in the form of a fluid driven rack and pinion 142 mounted to the actuator housing 57 by conventional means in lieu of the electrical motor 51. The rack and pinion is actuated by a transfer of fluid from an actuation cylinder 143. The actuation cylinder has a piston 144 that is forced from one end to the other end of the actuation cylinder 143 when the frame 20, 23, 34 is leaned relative to the lower arm 35. Movement of the piston 144 simultaneously transfers fluid through lines from one side of the rack and pinion 142 and to the other side of the rack and pinion 142. This plurality of lines is not necessary, but provides the advantage of redundancy. Thus, the rack and pinion is actuated and in turn drives the gears within the housing 57. This mechanical actuator drive 141 enables a user to manually actuate the lean of the vehicle by shifting his or her weight to lean the frame 20, 23, 34 towards the lower arm 35. As can be appreciated, a similar actuator drive mechanism 141 can be incorporated into each of the actuators and the actuation cylinder 143 can be placed at respective positions between the frame 20, 23, 34 and the actuator housings 57. A similar result could be achieved by alternative mechanical devices that include a set of gears, for example. The set of gears in this case would be set in motion by the user shifting his or her weight. Such a mechanical device could drive the gears in the housing 57 instead of the electrical motor 51 or the drive mechanism 141.

Further shown in the embodiment of Figure 4A, a position sensor 127 in the form of a potentiometer is fixedly mounted in the housing 57 proximate to a first connection pin 130. As shown in Figure 4E, which is a sectional view taken along lines 4E-4E of Figure 4A, the first connection pin 130 has a gear 133 fixed thereon. The first connection pin 130 is press fitted or otherwise fixed to the actuator arms 54, (as shown in Figure 3B). Thus, as the actuator arms are rotated, the first connection gear 133 is rotated through an equivalent angle. The first connection gear registers with a potentiometer gear 136 so that the angle of rotation of the actuator arm 54 is sensed by the potentiometer of the position sensor 127. The potentiometer is held in place on the housing by a bracket 139.

Loosening the bracket allows rotation of the potentiometer for proper calibration before tightening again. The potentiometer is an outboard position sensor since the angular movement between the actuator arm 54 and the housing correspond to the angular movement between the hub assembly 42 and the lower arm 35.

5 Alternatively, the potentiometer could be fixedly mounted to the lower arm 35 in alignment with the hub pin 93 and an input shaft 140 of the potentiometer could be non-rotatively coupled to an end of the hub pin 93 as shown in Figure 5. However, the outboard position sensor positioned thus could be more vulnerable to damage.

10 Figure 5 is a sectional view of the hub assembly 42 taken along lines 5-5 of Figure 3A. As shown, the hub pin 93 is press fit or otherwise fixed in the lower arm mount 145 of the hub assembly 42. The arm mount 145 and hub pin 93 have aligned through holes rotatively receiving a spindle pin 148 on a first axis 149. The arm mount 145 and hub pin 93 are rotatively connected to the outboard end of  
15 the lower arm 35 on a second axis 150. In the case of the outboard position sensor 127 being mounted in the actuator housing 57, the hub pin can be fixed to the lower arm 35 and rotatively received in the lower arm mount 145. In either case, the spindle housing 151 has two axes of rotational motion relative to the lower arm 35. A spherical bearing mount 152 rotatively connects an upper end of the hub assembly 42 to the upper control arm 36 so that it also has two axes of  
20 rotative motion relative to the upper control arm 36. Rotation of the spindle housing 151 about the second axis 150 is caused by movement of the upper control arm 36 relative to the lower arm 35 when actuated by the actuator 39. Rotation of the spindle housing about the first axis 149 is caused by a turning  
25 force applied to the armature 153. The turning force is applied by a tie rod end 154 connected to a hydraulic cylinder, which may be a conventional hydraulic cylinder. The armature 153 in this application has strengthening webs and/or other structure to withstand the strong turning loads that accompany large articulation angles about the two axes 149, 150. The loads can be especially large  
30 in racing and/or off-road applications.

Figure 6 is a top view of the rear swing arm frame 23 that can be used in applications such as with the vehicle 10 of Figure 1A. The rear swing arm frame 23 functions as a standard swing arm of a motorcycle and is mounted on a pivot pin 180. The swing arm frame 23 has a rear shock absorber 183 connected to the frame 23 and to the motorcycle analogous to standard rear shock absorbers in motorcycles. The swing arm frame 23 has a central opening 186 in which is disposed a differential 189. The differential is shown as a chain driven differential although a shaft driven differential is within the scope of the invention. The differential is connected to and drive half shafts 192 that are normally motively connected to the wheels, but which are shown cut away for illustrative purposes. The half shafts 192 may incorporate telescoping pieces and a plurality of universal or constant velocity joints to accommodate the great amount of articulation in the arm assemblies 25. The differential can be a positive traction differential incorporating unidirectional bearings, for example. Similarly, the front wheels could also be driving wheels driven by similar half shafts, and the front frame 20 could thus have an opening and incorporate a similar differential 189.

Figure 7 is a perspective view of a steering mechanism 200 that can be incorporated for controlling the rear steering in a vehicle of the present invention. The steering mechanism incorporates a rotary rack and pinion 205. The rack moves pistons in hydraulic cylinders 210. The pinion is actuated by a rear steering actuator motor 215 that can be integral with or added on to a rotary rack and pinion housing. The rear steering actuator motor 215 turns a worm gear 220 that engages an input shaft 225 of the rack and pinion 205. The input shaft 225, in turn, actuates the pinion of the rack and pinion 205. In this way, fluid is forced out of one of the cylinders 210 and moves a respective piston in cylinders that actuate tie rods. A rear steering position sensor, such as a potentiometer connected to the pinion shaft or a magnetic position sensor in one of the hydraulic cylinders (not shown in Figure 7), can sense the position of the steering. The rear steering position sensor 230 is operably associated with the other electric components of the system as shown in Figure 8. A similar steering mechanism can be implemented on a front steering of a vehicle of the present invention.

Figure 8 is block diagram showing various electrical and electronic components that can be implemented to a greater or lesser degree depending on the degree of automation desired. In the fully automated configuration, the frame(s) 20, 23, 34 and arm assemblies 25 are operably connected to an electronic control unit (ECU) 257. The ECU can be mounted anywhere on the frame(s) 20, 23, 34. Alternatively, the ECU can be mounted on the vehicle associated with suspension system. The ECU is operatively associated with the other electrical components for receiving feedback and sending control signals. For example the actuator motors 51 are connected to the processor via speed controllers 260. In this case, the actuator motors 51 can be speed controllable servomotors. The motors 51 can thus be controlled by a predetermined protocol provided by circuitry or a program in the ECU. The protocol includes a set of logical steps and responses based on input from the various electrical components.

The ECU 257 is advantageously utilized to accomplish a first major function of automatically leaning the frame 20, 23, 34 and wheels 28 in accordance with a particular speed and turning angle of the vehicle 10. To this end, the vehicle 10 is provided with a speed sensor 263 operatively associated with the ECU. The speed sensor 263 can be a device that senses revolutions per minute at the front wheel or at a selected location in the drive train. Alternatively, the speed sensor 263 could be a sensor that detects ground speed. A front steering position sensor 266 is provided in the form of a magnetic sensor in the hydraulic rams or as a potentiometer on the shaft of a rotary rack and pinion steering system both of which are known. Signals from the speed sensor 263 and the front steering position sensor 266 are transmitted to the ECU. The ECU processes the signals and calculates a proper angle of lean. Then the ECU sends a signal to the motors 51 to actuate the arm assemblies 25 to provide the proper angle of lean. In this case, all of the arm assemblies 25 will tilt in a common plane relative to the frame(s) 20, 23, 34. All of the wheels 28 and the frame(s) 20, 23, 34 will be at the same angle relative to this common plane. The arm assemblies 25 can be stopped at the proper lean angle based on a particular metered number of rotations or pulses by the motor 51. Alternatively, the arm assemblies 25 can be stopped at the

proper angle based on feedback from the outboard sensors 127. Further alternatively, the arm assemblies can be stopped at their proper angle based on a combination of metered input and feedback from sensors. Since the speed and angle of turn will generally vary continuously, the ECU 257 continuously receives  
5 signals, calculates an appropriate angle of lean, and actuates the motors via the speed controllers 260 in accordance with the predetermined protocol. Thus, the angle of lean is continuously adjusted.

Alternatively or additionally, one or more lean force sensors 269 are provided for sensing centrifugal and gravitational forces. The lean of the vehicle  
10 could be based exclusively on the feedback from a single lean force sensor 269 mounted inside the ECU housing, for example. Alternatively, a plurality of force sensors could be located at different positions in the vehicle, frame, and suspension. Feedback from such force sensors could be used to automatically balance the forces generally evenly or otherwise based on the predetermined  
15 protocol. The lean force sensors 269 could be used in addition to the speed and turning position sensors for redundancy and for additional feedback. It is to be understood that the feedback from the lean force sensors should be averaged over a sufficient period of time so as to not be significantly affected by changes in the contour of the driving surface.

Automatic adjustment of the angle of lean can be stopped by actuating a  
20 lean override switch 272 that is operatively associated with the ECU 257. Actuating the override switch 272 permits the angle of lean to be adjusted by the driver to a greater lean than the predetermined protocol provides, for example. Furthermore, the override switch 272 provides a safety feature in dealing with a  
25 power slide or other situations that commonly occur in riding. For example, when the automatic lean is a function of the turn angle, front counter steering in order to instantaneously pull out of a power slide could cause automatic lean in a direction radially outward relative to a curve being navigated. Such an automatic lean, in this case, is undesirable and could easily result in flipping the vehicle due to a  
30 shift in the center of gravity radially outward relative to the curve that is being

navigated. Thus, to prevent this, a driver can actuate the lean override switch before counter steering the front steering during a power slide. The override switch can take any of a variety of forms including, but not limited to, a rotatable left grip or a finger or thumb actuated lever. When lean is based on feedback from 5 lean force sensors 269, the need for a lean override may be eliminated since the system will attempt to balance the forces independent of front counter steering. However, the lean override feature may be included in a system with lean force sensors for additional control.

The lean override switch 272 can be configured with a single “off” and a 10 single “on” position for allowing a driver to simply take over control of lean by shifting his or her own weight when the override switch is in the “on” position. Alternatively, the override switch 272 can be implemented with plural discrete “on” settings or as a rheostat switch for continuous adjustment over a range of motion in the switch 272. It is to be understood that the lean override switch 272 15 can be configured to stop the movement of the actuator to hold the lean of the vehicle at any attitude. In the case of an override switch 272 having more than one on position, the switch 272 could be configured to provide manual actuation of the actuator motors 51 via the override switch 272 in order to lean the frame(s) 20, 23, 34 and vehicle 10 as desired.

20 The ECU 257 is used to accomplish a second major function of absorbing shock by actually tracking a contour of the surface 30. To this end, signals from the inboard and outboard sensors 50, 127 are fed back to the ECU 257 and are there compared. If the inboard position sensor 50 registers a greater deflection angle than the outboard position sensor 127, then the ECU actuates the motor 51 25 to make the outboard angle equivalent to the inboard angle in accordance with the predetermined protocol. This occurs, for example, when one of the arm assemblies 25 is independently raised by a bump. In this case, compression of the shock absorber 48 is initiated. However, as soon as this deflection of the arm assembly 25 begins, the difference between the inboard angle and the outboard angle is detected and the arm assembly is actuated to the position that 30

accommodates the bump. Because the feedback and actuation occurs very fast, the arm assembly is able to track up and over the bump with minimal compression of the shock absorber 48. Furthermore, a reduced amount of the load from the bump is transferred to the other side of the vehicle because the pertinent arm  
5 assembly has responsively moved up and over the bump. Once the bump has been passed, the arm assembly 25 immediately returns to the appropriate angle for a proper lean based on the current speed, and angle of turn or alternatively, based on the speed and angle of turn when the bump was first encountered. This shock absorption is provided by each of the arm assemblies 25 independently of each  
10 other. In this way, the frame and suspension system accomplishes both automatically leaning the frame(s) 20, 23, 34 and providing shock absorption by automatically tracking the contour of the surface 30 simultaneously.

It is to be understood that the outboard position sensors 127 could be eliminated altogether. The angle of the wheels 28 could be adjusted to coincide  
15 with an angle detected by the inboard sensor 50 when the arm assemblies 25 are moved to absorb a shock or to accommodate a bump in the contour of the driving surface 30.

It should be noted that this shock absorption by tracking is made possible in part by the speed capabilities of the motors 51. The motors 51 can be provided  
20 as servomotors that have an operating range of speeds from zero to approximately fifteen thousand revolutions per minute. At ten thousand revolutions per minute, twenty revolutions will only take a fraction of a second. With the present invention, it is also possible to move the arm assembly 25 through an angle of twenty-two and a half degrees in only a fraction of a second. It is to be understood  
25 that the speed of the actuator will vary based on the speed at which a bump is encountered, for example. In this way, the actuator motor speed will be automatically controlled to properly mirror the contour of the driving surface 30. The rate of the motors 51 will be adjusted so that they do not jar or shake the suspension and driver badly at their adjusted rate. In one configuration, the  
30 actuator motor speed can be adjusted to mirror the spring mechanism.

Alternatively, the actuator can be moved slightly slower than the spring compression rate of the shock absorbers 48 to allow movement of the suspension and accompanying feedback on which to base continuing adjustment.

Furthermore, the rate may be varied over the course of a single actuation to "ease"

5 the abruptness of stopping and starting a particular shock absorbing motion.

It should be further noted that the shock absorbers are needed to provide "feed forward" or to permit the initial difference between the outboard angle and the inboard angle. Another way to express what occurs during the tracking type of shock absorption is that the angle between the hub assembly 42 and the lower arm 10 35 reflects the proper angle of lean to accommodate a specific angle of turn at a specific speed in accordance with the predetermined protocol. When the angle between the lower arm and the frame(s) 20, 23, 34 becomes greater than or less than the outboard angle, then the actuators move the actuator arm 54 and the associated parallelogram structure including the hub assembly 42 and the upper 15 control arm 36 to match the inboard angle. Because of the parallelogram aspect of the arm assembly structure, the hub assembly 42 is automatically placed at the same angle as the inboard angle relative to the lower arm 35. As can be appreciated, the shock absorbers 48 are also important once the arm assembly 25 has reached an extreme in its range of motion. For example, when further relative 20 motion between the lower arm 35, upper control arm 36, and actuation arm 54 is physically limited, the shock absorber 48 can provide the needed deflection and shock absorption.

The above described tracking functions can further alternatively be provided by a more sophisticated forward looking system for mapping a contour 25 of the driving surface. Thus, the predetermined protocol could be configured to provide a pre-absorption of the shock of a bump, for example, by raising the wheels 28 just before they reach the bump.

It should be further noted that the frame and suspension system of the present invention is intended, at least in some cases, to provide a suspension on a

suspension. This is the case, for example, for a motorcycle body supported on frames 20, 23. In this case, conventional motorcycle shock absorbers are retained on the steering forks and on the rear swing arm frame 23. Thus, the motorcycle and driver 5 benefit from a non-conventional suspension on top of a suspension for and even smoother ride.

Rear steering can be implemented with any of the embodiments of the present invention. Rear steering capability is particularly beneficial in racing and other special applications. To this end, a rear steering position sensor can be operatively associated with the ECU. The rear steering actuator motor 215 is also operatively associated with and controlled by the ECU in accordance with the predetermined protocol. As with the other actuators set forth above, the rear steering actuator can be connected to the ECU by a speed controller 275. In this way, the speed of the rear steering motor and the position of the rear steering angle can be controlled automatically. The predetermined protocol can be configured to operate the rear steering mechanism by running the rear steering actuation motor 215 a set numbers of rotations or pulses, moving the rear steering actuator in accordance with feedback from the rear steering position sensor 230, or a combination of both. It is to be understood that the angle of turn for the rear steering can be in the same direction as the front steering and at a percentage of the front steering position. Although most applications call for the rear wheels to be turned only a small percentage of the front turn angle, it is possible to provide the rear turn angle at as much as one hundred percent of the front steering turn angle.

It is to be understood that the front steering position sensor 266 could be provided as a gyroscopic sensor or sensors that sense a change in the angle of lean of the vehicle by use of a gyroscope. In fact, an additional sensor or sensors could be provided in combination with the front steering sensor 266, or as a separate gyroscope for detecting attitude changes. Providing an attitude sensor in this way has the advantage of providing the system with a reference point. This could be particularly important when the driving surface is extremely steep, and especially

when the slope is in a side-to-side direction. In this case, the attitude sensor could actually provide feedback to enable the processor to maintain the frame and vehicle in an upright position when traveling in a straight line on a side-to-side inclined surface. This upright position could function as a reference orientation.

5 Gyroscopes and sensors for this purpose can be mounted anywhere on the vehicle or frame 20, 23, 34. The gyroscopes may be of the silicon type and be packaged with the ECU.

It is to be further understood that force sensors 281, 284 could be included in the front steering mechanism and operatively associated with the ECU 257.

10 The protocol controls an actuator in the hydraulic steering to decrease a flow of hydraulic fluid with increasing speed to provide a proper feel to the driver. As the required force increases due to restricted fluid flow, the force sensors detect the increased forces applied by the driver. Feedback from the force sensors 281, 284 is thus provided to the ECU, which in turn can effectuate an alternative or  
15 additional lean of the wheels 28. This aspect of the invention is considered to be particularly beneficial in applications in which the vehicle is a car.

In all applications the actuators, ECU, and other electrical components require a power source 287. It is contemplated that this power source could include a variety of batteries and capacitors to take advantage of the particular characteristics of each battery type and the capacitor. For example, in applications 20 in which the vehicle is a human powered vehicle, such as a bicycle, the power source could include nickel zinc batteries, lead acid batteries, and a capacitor in line with the batteries. The power source could be rechargeable, including recharging by regeneration.

25 Another convenient and useful aspect of the invention is the counter steering feature in which the rear steering is automatically turned in an opposite direction from the front steering. This enables a driver to make very tight turns and is typically utilized at low speeds. In the present invention, rear counter steering is actuated by pressing a momentary switch 278 that is operatively

associated with the ECU. That is, the switch must be held in an “on” position for as long as the rear counter steering feature is being implemented. When the momentary switch is held in the “on” position, the ECU automatically sends signals to the rear steering actuator 215 via the rear steering speed controller 275 to steer the rear wheels in an opposite direction relative to the front wheels in accordance with the predetermined protocol. Once again, the angle of turn of the rear counter steering is a percentage of the front steering angle, and can be selected between zero and one hundred percent. When the switch is released, the feature is automatically turned off and the rear steering automatically reverts to that provided by the predetermined protocol without the momentary switch being actuated.

It is to be understood that the automatic rear steering and counter steering can be provided as a function of the speed in the protocol. The exception is when the override switch is actuated, in which case the rear steering becomes a function of the lean.

It is to be further understood that the predetermined protocol can be adjusted or can include settings that can be selected. For example, it is possible to adjust the protocol or select a setting that turns “off” automatic rear steering. Furthermore, the protocol can be configured to provide the function of absorbing shock by automatically tracking a contour as discussed above, but to not provide the automatic lean adjustment. Automatic lean adjustment is particularly beneficial in application having a low center of gravity because it is more difficult for a driver to effect lean by shifting his or her body weight. However, the automatic lean feature can be incorporated in applications having high centers of gravity, such as with motorcycle having upright seating configurations. Advantageously, the present invention can be implemented with vehicles having any of a variety of occupant supporting configurations including, but not limited to, recumbent, prone, and kneeling.

The embodiments and examples set forth herein were presented in order to best explain the present invention and its practical application and to thereby enable those of ordinary skill in the art to make and use the invention. However, those of ordinary skill in the art will recognize that the foregoing description and examples have been presented for the purposes of illustration and example only.

5 The description as set forth is not intended to be exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are possible in light of the teachings above without departing from the spirit and scope of the forthcoming claims.

**CLAIMS**

- 1    1.    A suspension comprising:
  - 2           at least one arm assembly adapted to be connected to the frame;
  - 3           wherein the arm assembly comprises:
    - 4               a lower arm having an inboard end and an outboard end;
    - 5               an upper control arm having an inboard end and an outboard end;
  - 6           and
    - 7               an actuator mounted to the lower arm and motively connected to
    - 8               the upper control arm.
- 1    2.    The suspension of claim 1, wherein the actuator further comprises:
  - 2               an actuator arm pivotally connected to the inboard end of the upper control
  - 3               arm;
  - 4               the actuator arm pivotally connected to the inboard end of the lower arm;
  - 5           and
    - 6               an actuator motor motively connected to the actuator arm to move the
    - 7               actuator arm through a range of motion.
- 1    3.    The suspension of claim 2, further comprising a processor operably
  - 2               associated with
  - 3               the arm assembly and having circuitry or a program providing a predetermined
  - 4               protocol for automatically controlling the motor and the actuator arm.
- 1    4.    The suspension of claim 3, further comprising:
  - 2               a hub assembly pivotally connected to the outboard end of the lower arm;
  - 3               the hub assembly pivotally connected to the outboard end of the upper
  - 4               control arm; and
    - 5               at least one inboard position sensor located at a connection of the arm
    - 6               assembly that is adapted to be connected to the frame.

1 5. The suspension of claim 4, further comprising at least one outboard position  
2 sensor  
3 located at a connection between the arm assembly and the hub assembly.

4 6. The suspension of claim 4, further comprising at least one outboard position  
5 sensor  
6 connected to the actuator.

1 7. The suspension of claim 6, wherein the predetermined protocol further  
2 comprises a  
3 control for operating the actuator independently and adapted to track contours of a  
4 surface on which the suspension rests, wherein:  
5 the inboard position sensor relays an actual angular position of the lower  
6 arm;  
7 the outboard position sensor relays an angle of the hub assembly reflecting  
8 a lean angle; and  
9 the processor actuates the actuator motor of the arm assembly  
10 independently moves the hub assembly to effectively track the contour.

1 8. The suspension of claim 6, wherein:  
2 the arm assembly is one of a pair of rear arm assemblies;  
3 the arm assembly further has a rear steering mechanism; and  
4 the processor automatically controls a position of the rear steering  
5 mechanism in accordance with the predetermined protocol in the processor based  
6 on a lean angle as reflected by data from the plurality of outboard position sensors  
7 of the plurality of arm assemblies.

1 9. The suspension of claim 8, further comprising:  
2 a momentary switch operatively associated with the processor;  
3 wherein the processor is configured to control the rear steering mechanism  
4 in counter steering angles in accordance with the predetermined protocol when the  
5 momentary switch is actuated.

1    10.    The suspension of claim 3, further comprising:  
2                at least one speed sensor operably associated with the processor and  
3                adapted for detecting a vehicle speed;  
4                at least one front steering position sensor operably associated with the  
5                processor and adapted for determining an angle of turn; and  
6                wherein the speed sensor and the front steering position sensor provide data  
7                to the processor, and the processor controls the motor in the arm assembly and  
8                moves the actuator arm in a manner adapted to provide lean of the frame relative to  
9                the arm assembly in accordance with the predetermined protocol.

1    11.    The suspension of claim 3, adapted to be connected to a frame, wherein the  
2                frame has a central longitudinal axis and an upright axis that is adapted to be  
3                generally perpendicular to a ground surface when the frame is in a neutral position  
4                with no net leaning loads applied, the suspension further comprising:  
5                a lean override switch connected to the processor adapted to permit  
6                manually leaning the frame to an angle greater than that automatically provided by  
7                the predetermined protocol relative to the upright axis of the frame.

1    12.    The suspension of claim 11, wherein:  
2                the processor is configured to cease automatically controlling an angle of  
3                lean based on the angle of turn and the speed of the vehicle while the lean override  
4                switch is actuated so that the front steering can be counter steered such as in the  
5                case of a power slide; and  
6                the lean ceases to be automatically changed while the override switch is  
7                actuated.

1    13.    The vehicle of claim 11, wherein the processor is configured to once again  
2                begin  
3                automatically controlling an angle of lean based on the angle of turn and the speed  
4                of the vehicle when the override switch is released.

1    14.    The suspension of claim 8, wherein the processor is configured to move the  
2                 actuator  
3                 arm in a manner adapted to rotate the arm assembly during deceleration in order to  
4                 lower the frame and provide a lower center of gravity of the vehicle.

1    15.    The suspension of claim 2, further comprising:  
2                 a shock absorber having an inboard end and an outboard end;  
3                 the inboard end of the shock absorber adapted to be connected to the frame;  
4                 and  
5                 the outboard end of the shock absorber connected to the actuator arm.

1    16.    The suspension of claim 15, wherein the shock absorber is connected to the  
2                 actuator  
3                 arm outboard relative to a position at which the upper control arm is connected to  
4                 the actuator arm.

1    17.    The suspension of claim 15, wherein the outboard end of the shock  
2                 absorber moves in  
3                 a range of motion between a position generally above the upper control arm to a  
4                 position generally below the upper control arm.

1    18.    The suspension of claim 2, wherein the actuator arm comprises:  
2                 a first connection comprising structure that pivotally connects the actuator  
3                 arm to the lower arm;  
4                 a second connection comprising structure that pivotally connects the  
5                 actuator arm to the upper control arm;  
6                 a third connection that connects a shock absorber to the actuator arm; and  
7                 wherein a line through the first connection and the second connection is at  
8                 an angle in a range substantially from 0 to 90 degrees relative to a line through the  
9                 first connection and the third connection.

1 19. The suspension of claim 18, wherein the angle is approximately forty-five  
2 degrees.

1 20. The suspension of claim 18, wherein the third connection is outboard of the  
2 second connection.

1 21. A frame and suspension for a vehicle comprising:  
2 a frame having a central longitudinal axis and an upright axis;  
3 a suspension comprising a plurality of arm assemblies connected to the  
4 frame;  
5 wherein each arm assembly comprises:  
6 a lower arm having an inboard end and an outboard end;  
7 an upper control arm having an inboard end and an outboard end;  
8 and  
9 an actuator motively connected to the upper control arm.

1 22. The frame and suspension of claim 21, wherein the actuator further  
2 comprises:  
3 an actuator arm pivotally connected to the inboard end of the upper control  
4 arm;  
5 the actuator arm pivotally connected to the inboard end of the lower arm;  
6 and  
7 an actuator motor supported on the lower arm and motively connected to  
8 the actuator arm to move the actuator arm through a range of motion.

1 23. The frame and suspension of claim 22, further comprising a processor  
2 operably  
3 associated with each arm assembly and having circuitry or a program providing a  
4 predetermined protocol for automatically controlling the motor and the actuator  
5 arm.

1    24.    The frame and suspension of claim 23, further comprising:  
2                 a hub assembly pivotally connected to the outboard end of the lower arm;  
3                 the hub assembly pivotally connected to the outboard end of the upper  
4                 control arm; and  
5                 a plurality of inboard position sensors located at connections between the  
6                 arm assemblies and the frame.

1    25.    The frame and suspension of claim 24, further comprising a plurality of  
2                 outboard  
3                 position sensors located at connections between the arm assemblies and the hub  
4                 assemblies.

1    26.    The frame and suspension of claim 24, further comprising a plurality of  
2                 outboard  
3                 position sensors connected to the actuators.

1    27.    The frame and suspension of claim 26, wherein the predetermined protocol  
2                 further  
3                 comprises a control for operating each of the actuators independently and adapted  
4                 to track contours of the surface on which the frame and suspension rests, wherein:  
5                 each inboard position sensor relays an actual angular position of the lower  
6                 arm relative to the frame;  
7                 each outboard position sensor relays an angle of the hub assembly reflecting  
8                 a lean angle based on a speed and a turn angle of the frame and suspension; and  
9                 the processor actuates the actuator motor of each arm assembly  
10                independently of each other and moves each respective hub assembly parallel to the  
11                frame in a manner adapted to effectively track the contour.

1 28. The frame and suspension of claim 26, wherein:  
2 the plurality of arm assemblies comprise at least two rear arm assemblies;  
3 the two rear arm assemblies have a rear steering mechanism; and  
4 the processor automatically controls a position of the rear steering  
5 mechanism in accordance with the predetermined protocol in the processor based  
6 on a lean angle as reflected by data from the plurality of outboard position sensors  
of the plurality of arm assemblies.

1 29. The frame and suspension of claim 28, further comprising:  
2 a momentary switch operatively associated with the processor;  
3 wherein the processor is configured to control the rear steering mechanism  
4 in counter steering angles in accordance with the predetermined protocol when the  
momentary switch is actuated.

1 30. The frame and suspension of claim 23, further comprising:  
2 at least one speed sensor operably associated with the processor and  
3 adapted for detecting the vehicle speed;  
4 at least one front steering position sensor operably associated with the  
5 processor and adapted for determining an angle of turn; and  
6 wherein the speed sensor and the front steering position sensor provide data  
7 to the processor, and the processor controls the motor in each arm assembly and  
8 moves the actuator arms to provide a lean of the frame relative to the arm  
9 assemblies in accordance with the predetermined protocol.

1 31. The frame and suspension of claim 23, wherein the frame and suspension  
2 further has a  
3 lean override switch connected to the processor to permit manually leaning the  
4 frame to an angle greater than that automatically provided by the predetermined  
5 protocol relative to the upright axis of the frame.

1    32.    The frame and suspension of claim 31, wherein:  
2                 the processor is configured to cease automatically controlling an angle of  
3        lean based on the angle of turn and the speed of the frame and suspension while the  
4        lean override switch is actuated so that the front steering can be counter steered  
5        such as in the case of a power slide; and  
6                 the lean ceases to be automatically changed while the override switch is  
7        actuated.

1    33.    The frame and suspension of claim 31, wherein the processor is configured  
2        to once  
3        again begin automatically controlling an angle of lean based on the angle of turn  
4        and the speed of the frame and suspension when the override switch is released.

1    34.    The frame and suspension of claim 23, wherein the processor is configured  
2        to move the  
3        actuator arms so that the arm assemblies rotate generally inwardly toward each  
4        other during deceleration in order to lower the frame therebetween and provide a  
5        lower center of gravity.

1    35.    The frame and suspension of claim 22, further comprising:  
2        a shock absorber having an inboard end and an outboard end;  
3        the inboard end of the shock absorber connected to the frame; and  
4        the outboard end of the shock absorber connected to the actuator arm.

1    36.    The frame and suspension of claim 35, wherein the shock absorber is  
2        connected to the  
3        actuator arm outboard relative to a position at which the upper control arm is  
4        connected to the actuator arm.

1    37.    The suspension of claim 35, wherein the outboard end of the shock  
2       absorber moves in a range of motion between a position generally above the  
     upper control arm to a position generally below the upper control arm.

1    38.    The frame and suspension of claim 22, wherein the actuator arm comprises:  
2       a first connection comprising structure that pivotally connects the actuator  
3       arm to the lower arm;  
4       a second connection comprising structure that pivotally connects the  
5       actuator arm to the upper control arm;  
6       a third connection that connects a shock absorber to the actuator arm; and  
7       wherein a line through the first connection and the second connection is at  
8       an angle in a range substantially from 0 to 90 degrees relative to a line through the  
     first connection and the third connection.

1    39.    The frame and suspension of claim 38, wherein the angle is approximately  
2       forty-five degrees.

1    40.    The frame and suspension of claim 38, wherein the third connection is  
2       outboard of the  
3       second connection.

1    41.    A vehicle with a lean and alignment control system, comprising:  
2                 a frame having a central longitudinal axis and an upright axis that is  
3                 adapted to be generally perpendicular to a surface on which the vehicle rests when  
4                 the frame is in a neutral position with no net leaning loads applied;  
5                 a vehicle body supported on the frame;  
6                 a suspension comprising a plurality of arm assemblies connected to the  
7                 frame;  
8                 wherein each arm assembly comprises:  
9                         a lower arm having an inboard end and an outboard end;  
10                  an upper control arm having an inboard end and an outboard end;  
11                  and  
12                  an actuator mounted to the lower arm and motively connected to the  
13                  upper control arm.

1    42.    The vehicle of claim 41, wherein the actuator further comprises:  
2                 an actuator arm pivotally connected to the inboard end of the upper control  
3                 arm;  
4                 the actuator arm pivotally connected to the inboard end of the lower arm;  
5                 and  
6                 an actuator motor motively connected to the actuator arm to move the  
7                 actuator arm through a range of motion.

1    43.    The vehicle of claim 42, further comprising a processor operably associated  
2                 with each  
3                 arm assembly and having circuitry or a program providing a predetermined  
4                 protocol for automatically controlling the motor and the actuator arm.

1    44.    The vehicle of claim 43, wherein the plurality of arm assemblies comprises:  
2                at least a first arm assembly on a first side of the frame;  
3                at least a second arm assembly on a second side opposite to the first side;  
4        and  
5                wherein the processor automatically moves the frame through a first lean  
6        angle closer to the first arm assembly and away from the second arm assembly so  
7        that the first and second arm assemblies remain generally parallel to each other.

1    45.    The vehicle of claim 43, further comprising:  
2                a hub assembly pivotally connected to the outboard end of the lower arm;  
3                the hub assembly pivotally connected to the outboard end of the upper  
4        control arm; and  
5                a plurality of inboard position sensors located at connections between the  
6        arm assemblies and the frame.

1    46.    The vehicle of claim 45, further comprising a plurality of outboard position  
2        sensors  
3        located at connections between the arm assemblies and the hub assemblies.

1    47.    The vehicle of claim 45, further comprising a plurality of outboard position  
2        sensors  
3        connected to the actuators.

1 48. The vehicle of claim 47, wherein the predetermined protocol further  
2 comprises a  
3 control for operating each of the actuators independently and adapted to track  
4 contours of the surface on which the vehicle rests, wherein:  
5       each inboard position sensor relays an actual angular position of the lower  
6 arm relative to the frame;  
7       each outboard position sensor relays an angle of the hub assembly reflecting  
8 a lean angle based on a speed and a turn angle of the vehicle; and  
9       the processor actuates the actuator motor of each arm assembly  
10 independently of each other and moves each respective hub assembly parallel to the  
11 frame to effectively track the contour.

1 49. The vehicle of claim 47, wherein:  
2       the plurality of arm assemblies comprise at least two rear arm assemblies;  
3       the two rear arm assemblies have a rear steering mechanism; and  
4       the processor automatically controls a position of the rear steering  
5 mechanism in accordance with the predetermined protocol in the processor based  
6 on a lean angle as reflected by data from the plurality of outboard position sensors  
7 of the plurality of arm assemblies.

1 50. The vehicle of claim 49, further comprising:  
2 a momentary switch operatively associated with the processor;  
3 wherein the processor is configured to control the rear steering mechanism  
4 in counter steering angles in accordance with the predetermined protocol when the  
5 momentary switch is actuated.

1 51. The vehicle of claim 43, further comprising:  
2 at least one speed sensor operably associated with the processor and  
3 adapted for detecting the vehicle speed;  
4 at least one front steering position sensor operably associated with the  
5 processor and adapted for determining an angle of turn; and  
6 wherein the speed sensor and the front steering position sensor provide data  
7 to the processor, and the processor controls the motor in each arm assembly and  
8 moves the actuator arms to provide a lean of the frame relative to the arm  
9 assemblies in accordance with the predetermined protocol.

1 52. The vehicle of claim 43, wherein the vehicle further has a lean override  
2 switch  
3 connected to the processor to permit manually leaning the frame and the vehicle  
4 body to an angle greater than that automatically provided by the predetermined  
5 protocol relative to the upright axis of the frame.

1 53. The vehicle of claim 52, wherein:  
2 the processor is configured to cease automatically controlling an angle of  
3 lean based on the angle of turn and the speed of the vehicle while the lean override  
4 switch is actuated so that the front steering can be counter steered such as in the  
5 case of a power slide; and  
6 the lean ceases to be automatically changed while the override switch is  
7 actuated.

1 54. The vehicle of claim 52, wherein the processor is configured to once again  
2 begin  
3 automatically controlling an angle of lean based on the angle of turn and the speed  
4 of the vehicle when the override switch is released.

1    55.    The vehicle of claim 43, wherein the processor is configured to move the  
2                 actuator arms  
3                 so that the arm assemblies rotate generally inwardly toward each other during  
4                 deceleration in order to lower the frame therebetween and provide a lower center of  
5                 gravity for the vehicle.

1    56.    The vehicle of claim 42, further comprising:  
2                 a shock absorber having an inboard end and an outboard end;  
3                 the inboard end of the shock absorber connected to the frame; and  
4                 the outboard end of the shock absorber connected to the actuator arm.

1    57.    The vehicle of claim 56, wherein the shock absorber is connected to the  
2                 actuator arm  
3                 outboard relative to a position at which the upper control arm is connected to the  
4                 actuator arm.

1    58.    The vehicle of claim 56, wherein the shock absorber moves in a range of  
2                 motion  
3                 between:  
4                 a first position in which the shock absorber extends in an end to end  
5                 direction substantially parallel with the lower arm of a first arm assembly of the  
6                 plurality of arm assemblies when the frame is leaned away from the first arm  
7                 assembly; and  
8                 a second position having an angle of approximately forty-five degrees  
9                 relative to the lower arm of the first arm assembly when the frame is leaned toward  
10                the first arm assembly.

1    59.    The suspension of claim 56, wherein the outboard end of the shock  
2                 absorber moves in  
3                 a range of motion between a position generally above the upper control arm to a  
4                 position generally below the upper control arm.

- 1    60.    The vehicle of claim 42, wherein the actuator arm comprises:  
2                 a first connection comprising structure that pivotally connects the actuator  
3         arm to the lower arm;  
4                 a second connection comprising structure that pivotally connects the  
5         actuator arm to the upper control arm;  
6                 a third connection that connects a shock absorber to the actuator arm; and  
7                 wherein a line through the first connection and the second connection is at  
8         an angle in a range substantially from 0 to 90 degrees relative to a line through the  
9         first connection and the third connection.
- 1    61.    The vehicle of claim 60, wherein the angle is approximately forty-five  
2         degrees.
- 1    62.    The vehicle of claim 60, wherein the third connection is outboard of the  
2         second  
3         connection.
- 1    63.    The vehicle of claim 43, further comprising at least one attitude sensor  
2         connected to  
3         the arm assembly and adapted for detecting a grade of a surface on which the  
4         vehicle is supported.
- 1    64.    The vehicle of claim 41, wherein the actuator further comprises a  
2         mechanical actuator  
3         drive mechanism including:  
4                 a rack and pinion; and  
5                 an actuator cylinder in fluid communication with the rack and pinion for  
6         manually driving the rack and pinion and the actuator.

1 65. A method of properly leaning and aligning a vehicle supported on a  
2 suspension, the method comprising automatically leaning a frame of the  
3 vehicle at a predetermined angle relative to an arm of one of a plurality of  
4 arms assemblies.

1 66. The method of properly leaning and aligning of claim 65, wherein the step  
2 of  
3 automatically leaning further comprises:  
4 providing a protocol in a processor;  
5 automatically feeding data from a vehicle speed sensor and a steering  
6 position sensor to the processor; and  
7 automatically moving the frame relative to the arm according to the  
8 protocol under processor control.

1 67. The method of claim 65, further comprising:  
2 automatically orienting rear wheels of the vehicle at an angle related to an  
3 angle of turn of at least one front wheel by a processor in accordance with a  
4 predetermined protocol in the processor.

1 68. The method of claim 67, wherein the step of automatically orienting the  
2 rear wheels  
3 further comprises automatically orienting the rear wheels at an angle opposite to  
4 the at least one front wheel by actuating a momentary switch operatively associated  
5 with the processor.

1 69. The method of claim 67, wherein the step of automatically orienting further  
2 comprises:  
3 providing a protocol in a processor;  
4 automatically feeding data from a vehicle speed sensor and a front steering  
5 position sensor to the processor; and  
6 automatically orienting the rear wheels according to the protocol under  
7 processor control.

1    70.    The method of properly leaning and aligning of claim 65, wherein the angle  
2    is a first of a plurality of angles, and the step of automatically leaning is a first of a  
3    plurality of continuous steps of leaning in the plurality of angles, so that the frame  
4    is automatically and continuously moved through a series of the plurality of angles  
5    based on the speed and angle of turn of the vehicle.

1    71.    The method of properly leaning and aligning of claim 65, further  
2    comprising:    automatically feeding back data representing a position of the arm  
3    relative to the frame; and  
4                automatically stopping the lean when the relative position meets a  
5    predetermined criteria.

1    72.    In a vehicle, a method of tracking a contour of a driving surface to absorb  
2    shock, the method comprising automatically and independently raising and  
3    lowering a plurality of arms of the vehicle suspension to accommodate variations  
4    in the contour.

1    73.    The method of claim 72, further comprising:  
2                providing feed forward by a mechanical shock absorber; providing feedback  
3    to a processor; and raising and lowering the arms according to the feedback under  
4    processor control.

\* \* \* \*

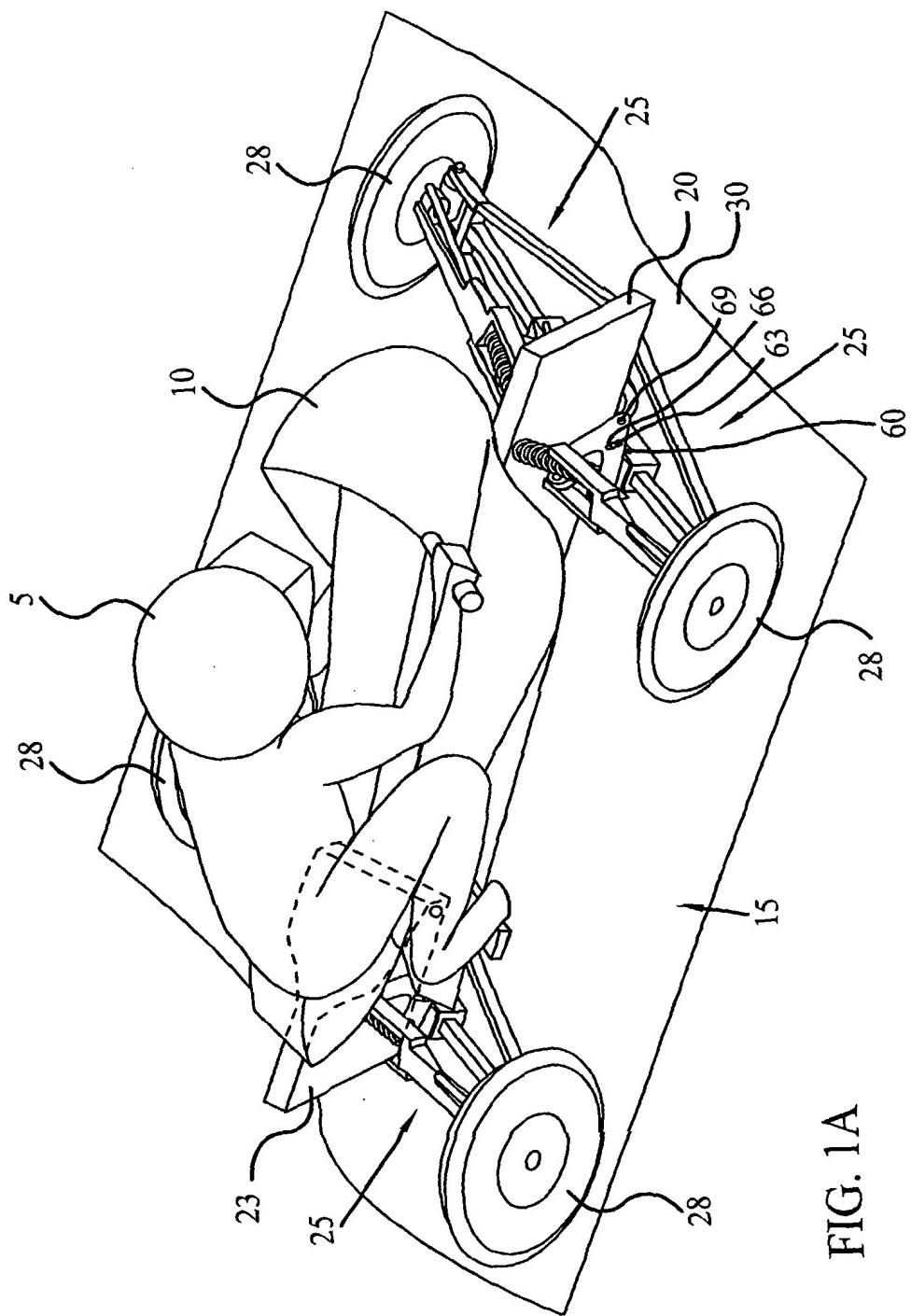


FIG. 1A

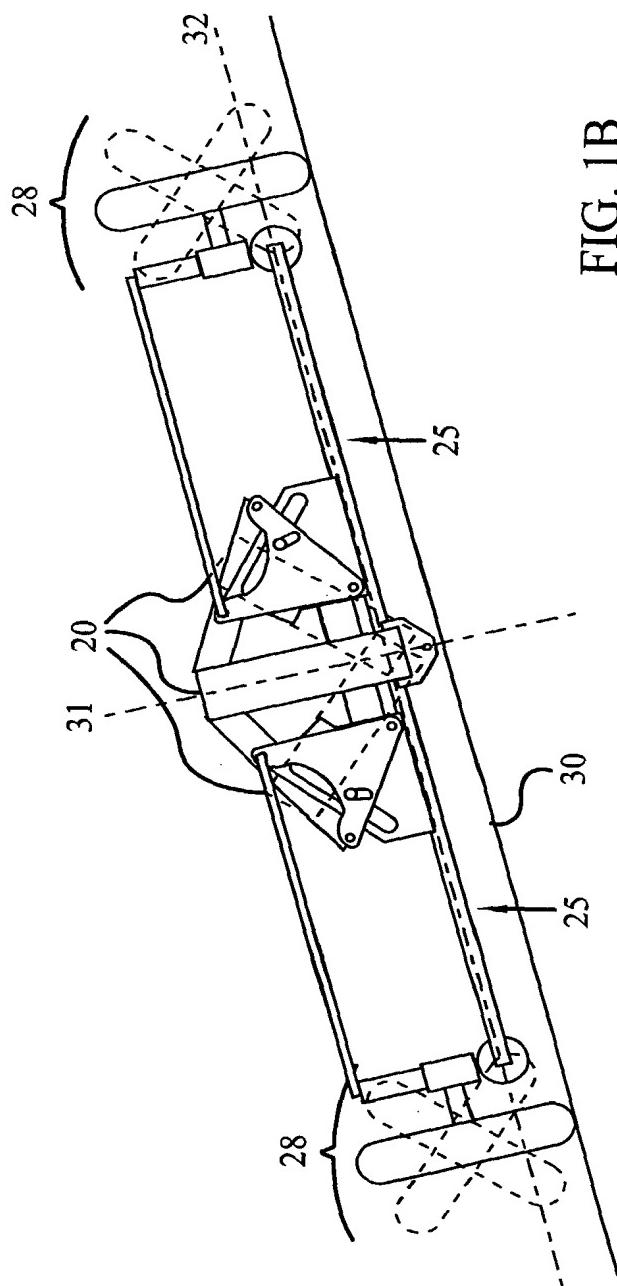


FIG. 1B

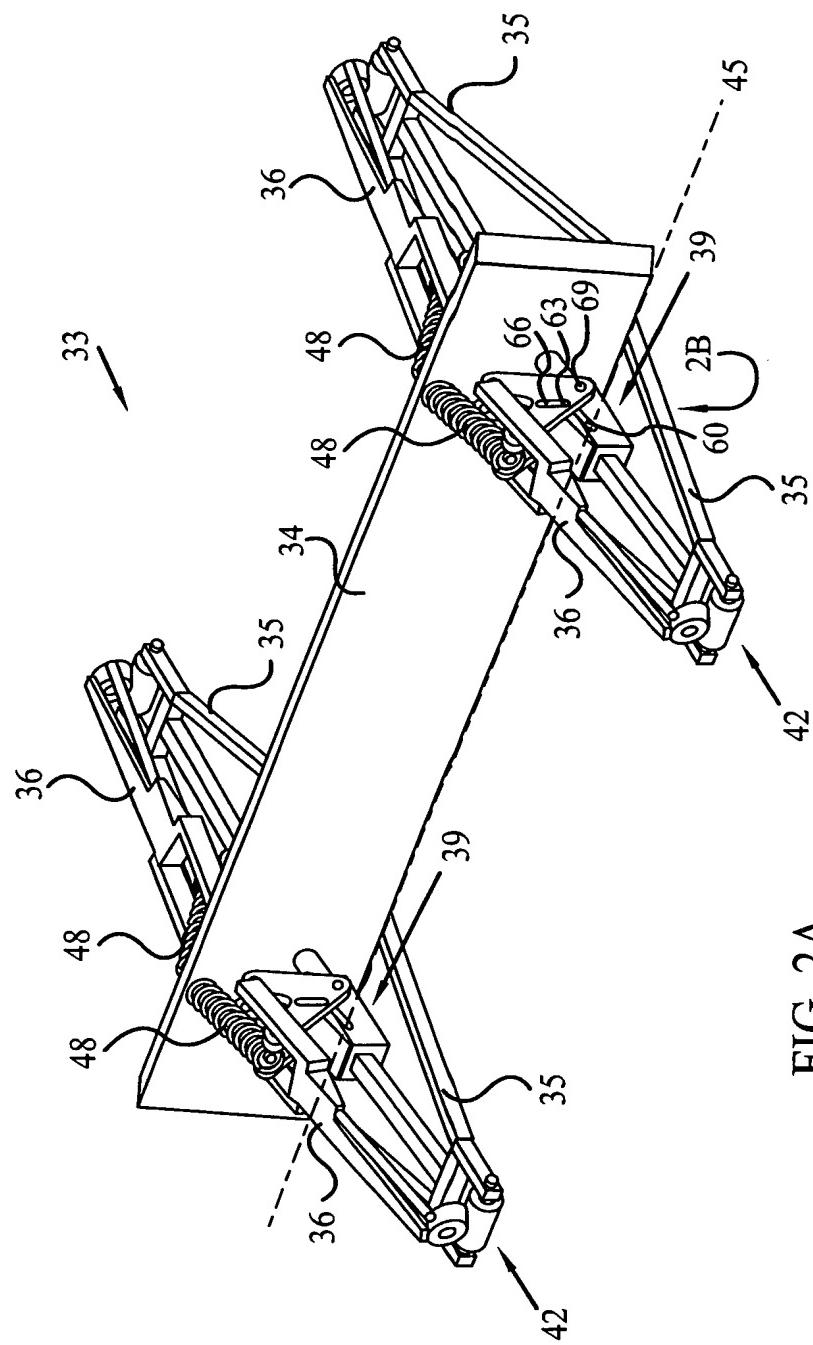


FIG. 2A

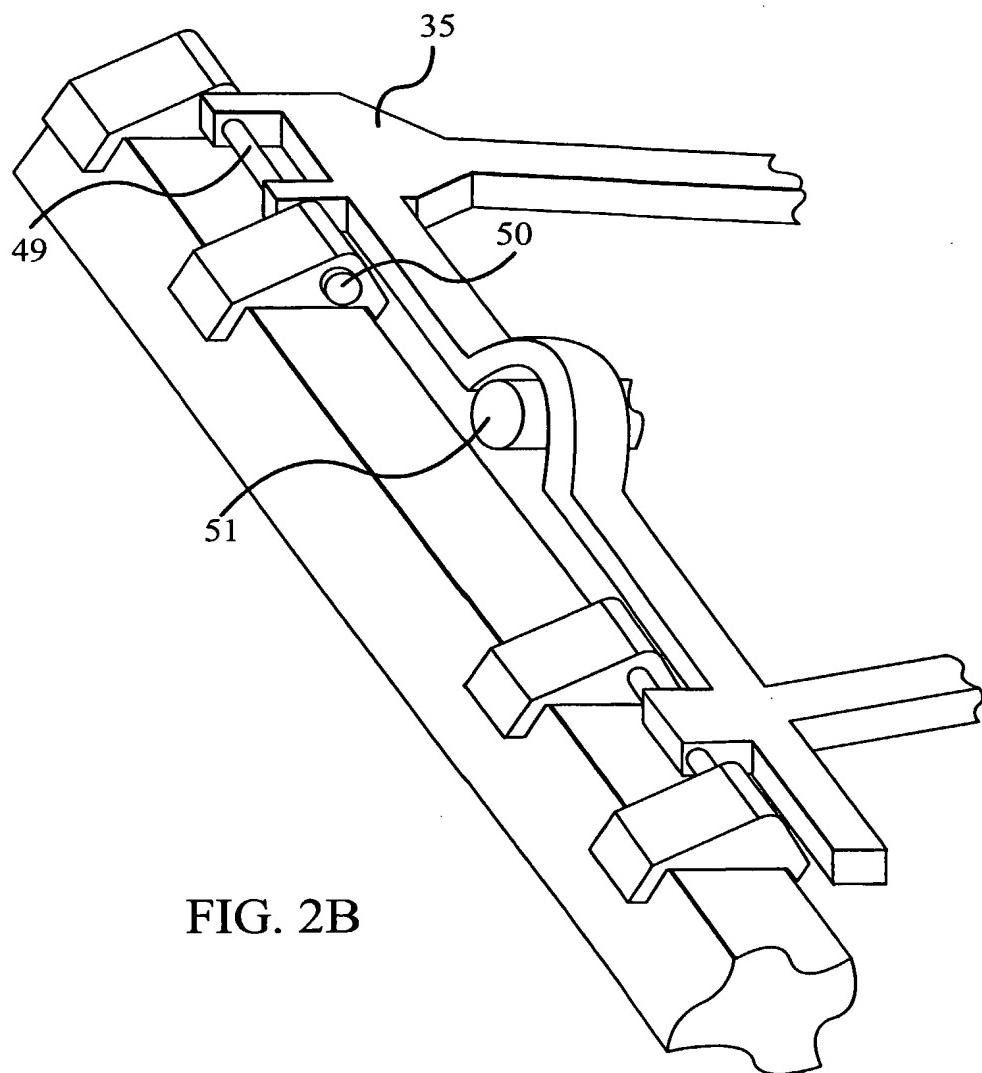


FIG. 2B

FIG. 3A

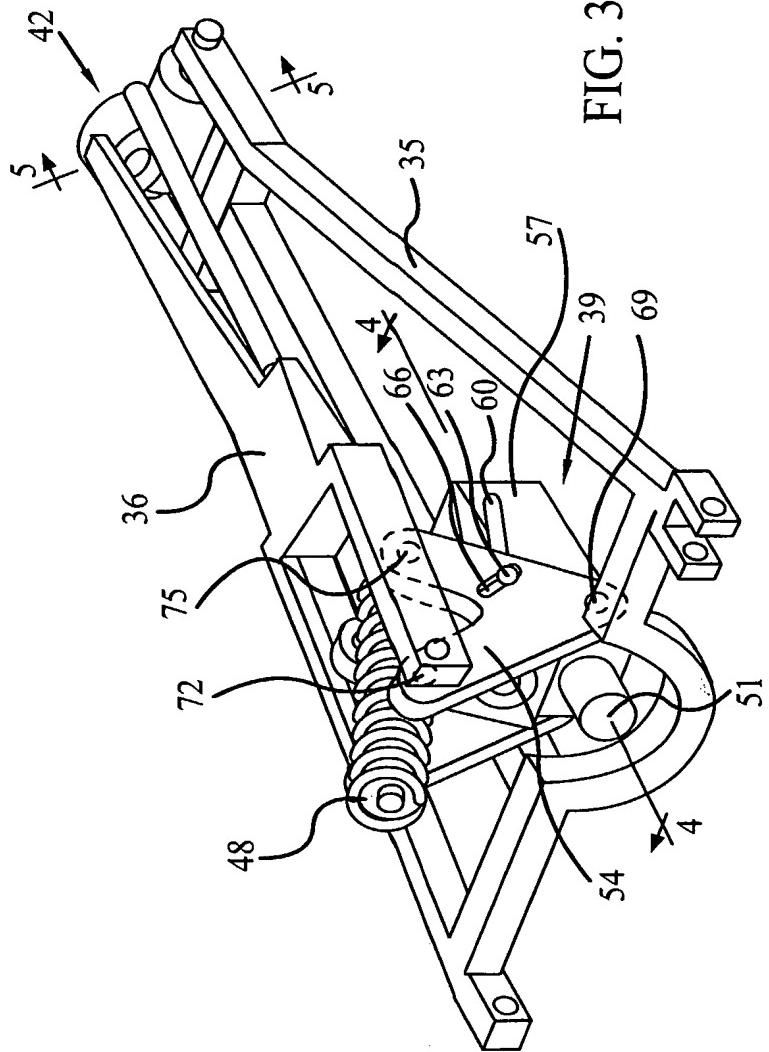
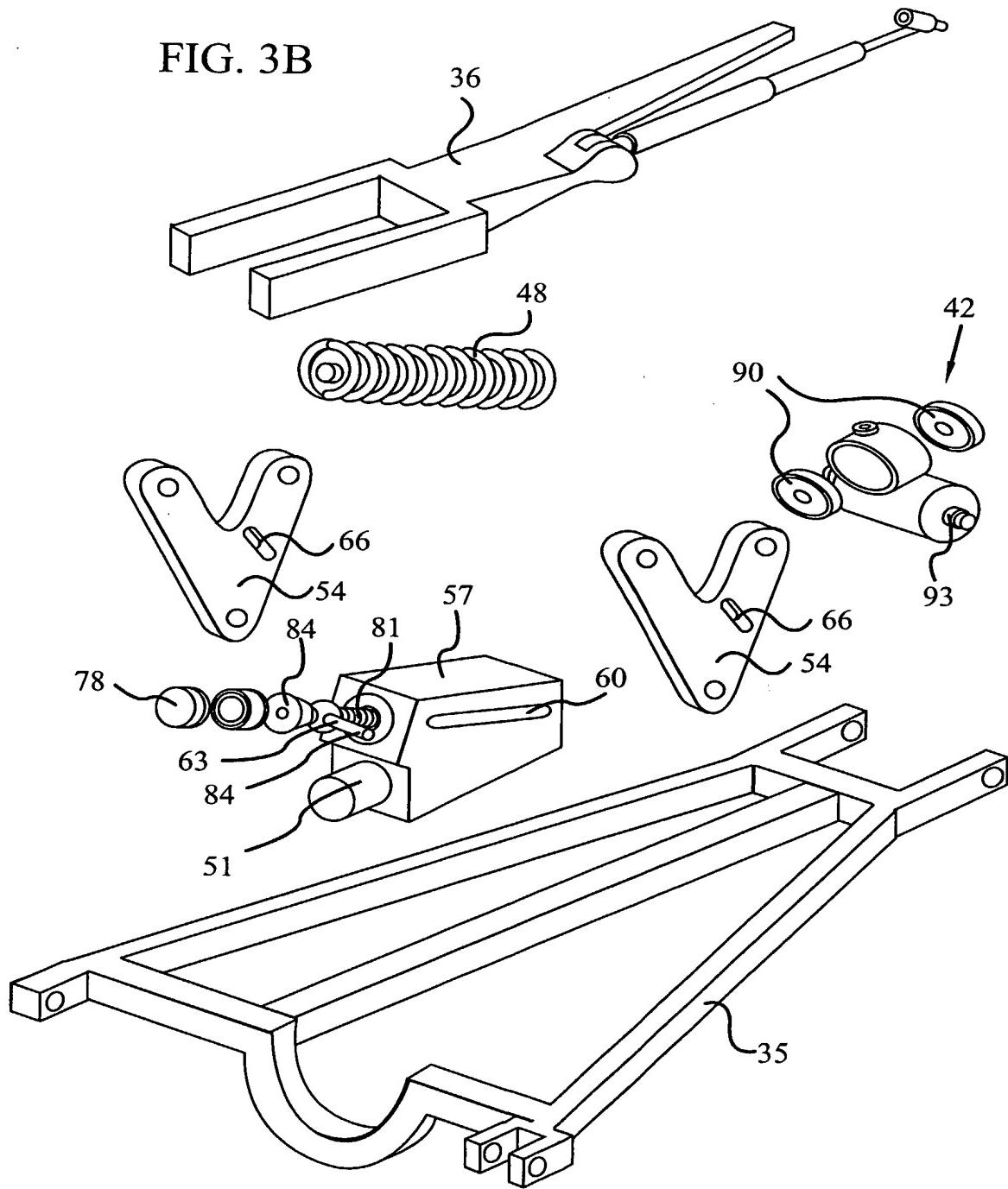
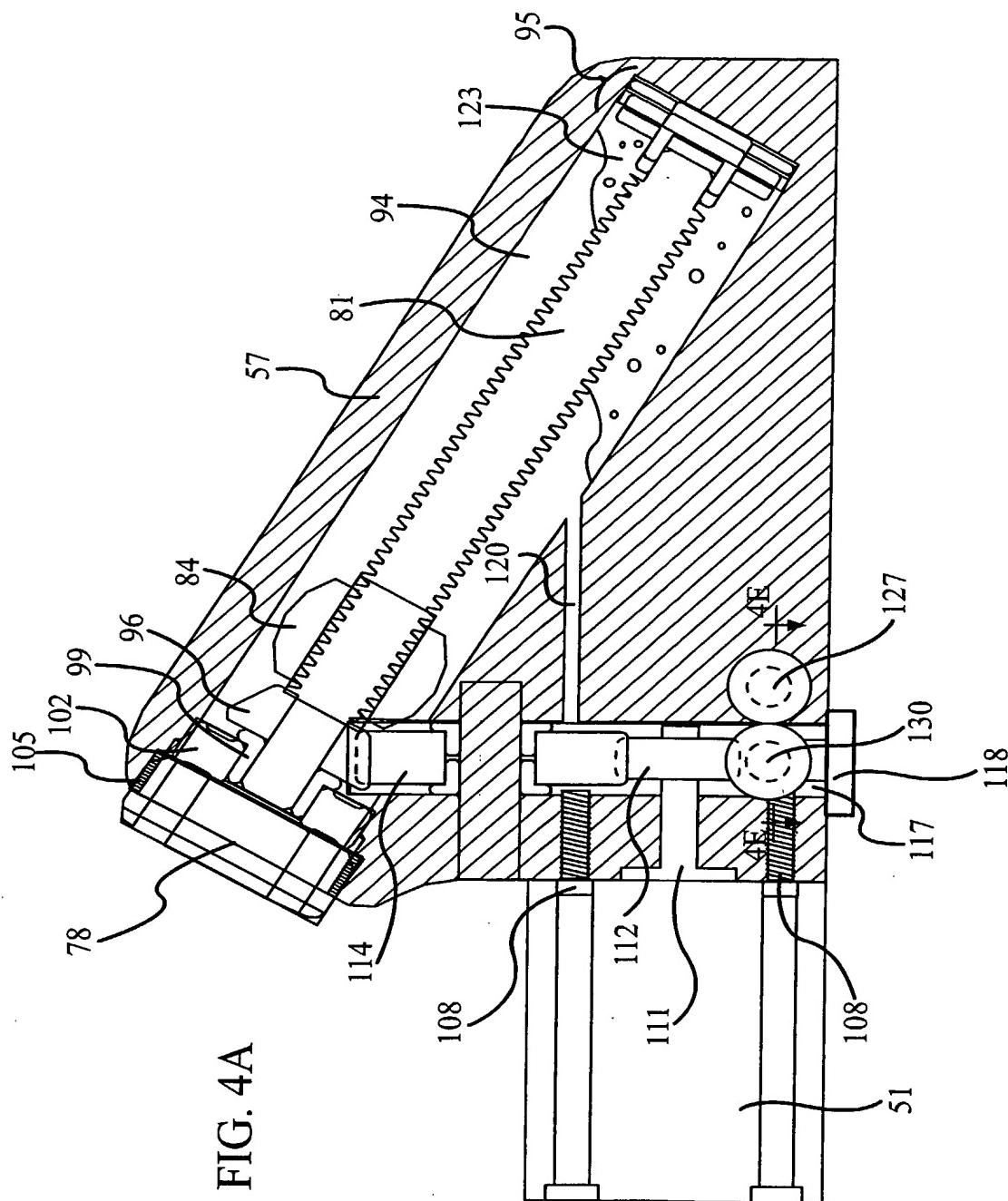


FIG. 3B





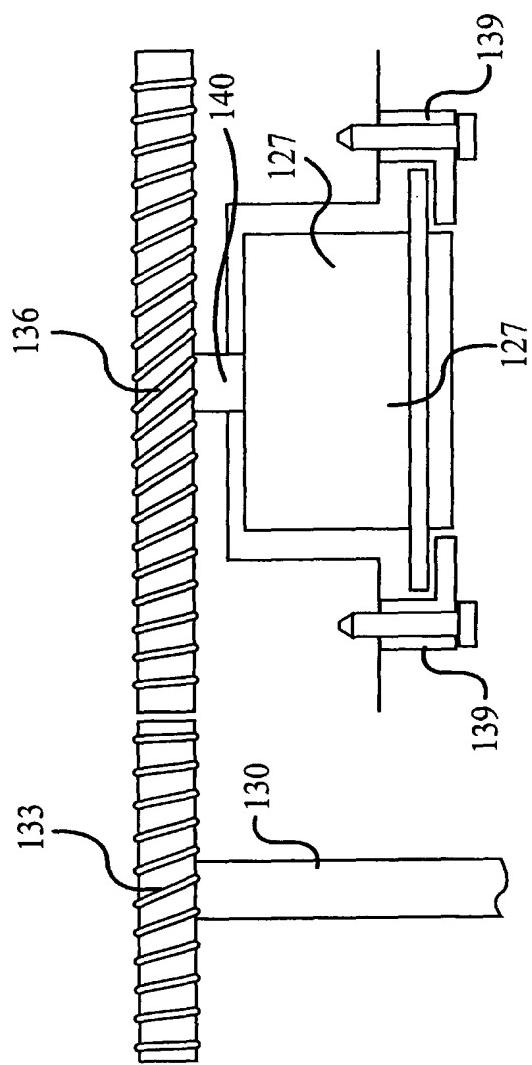


FIG. 4E

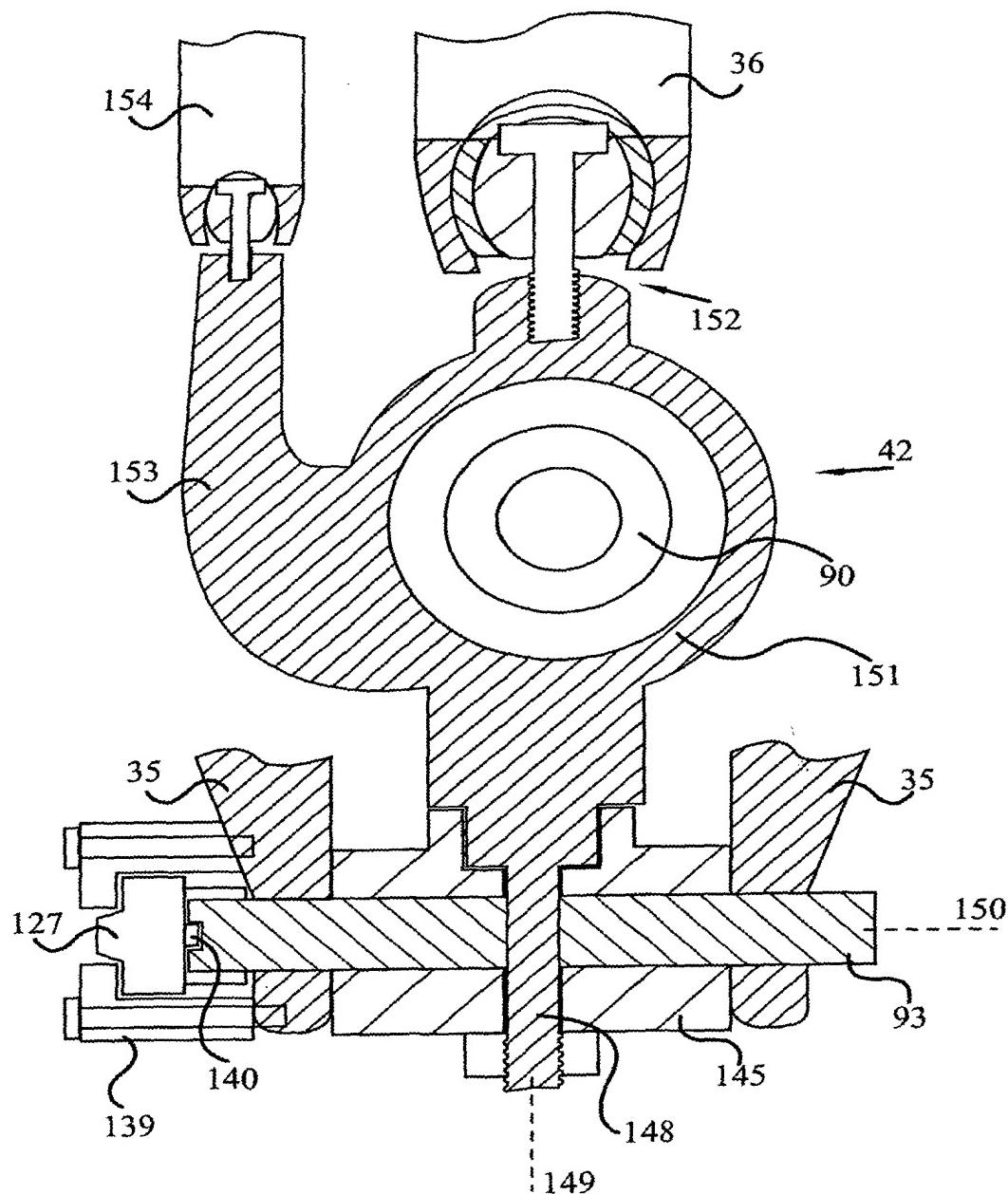


FIG. 5

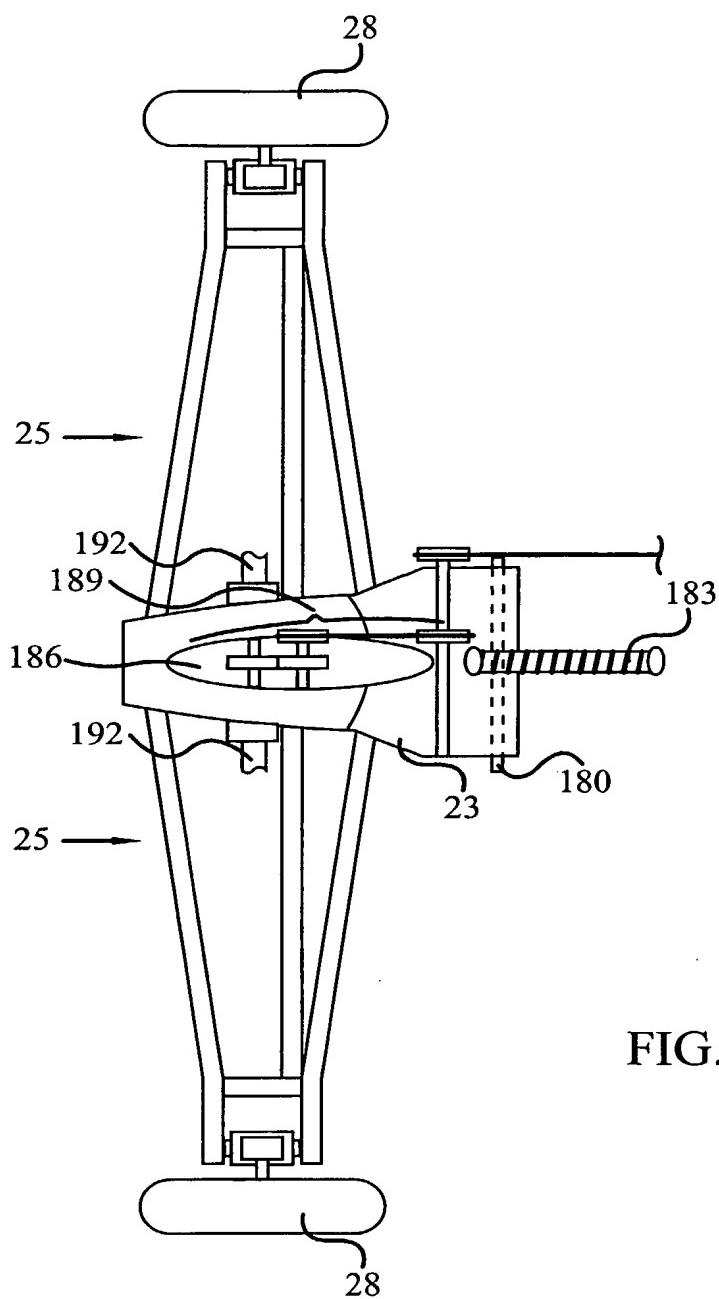
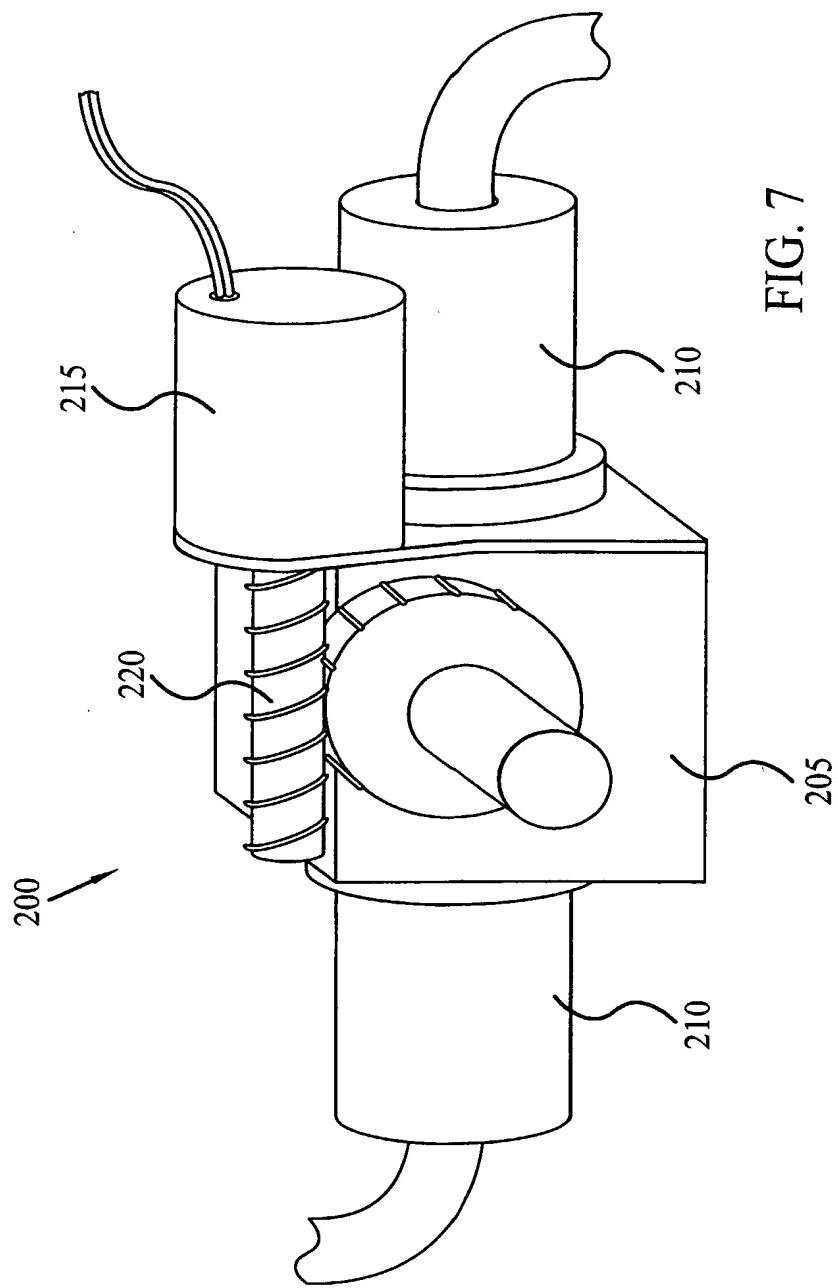


FIG. 6



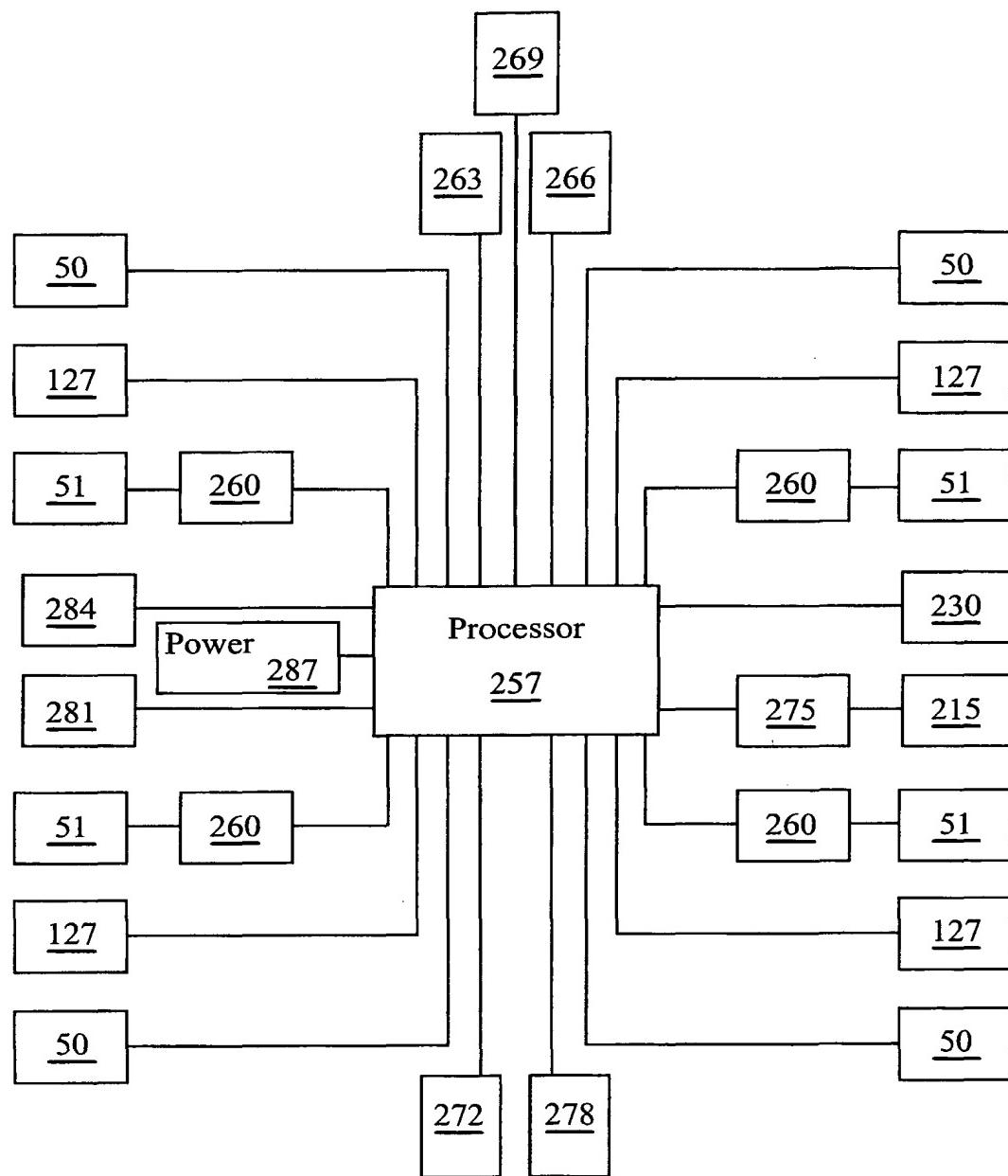


FIG. 8

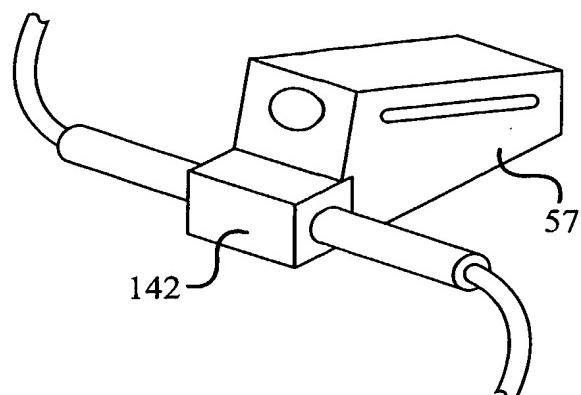


FIG. 4B

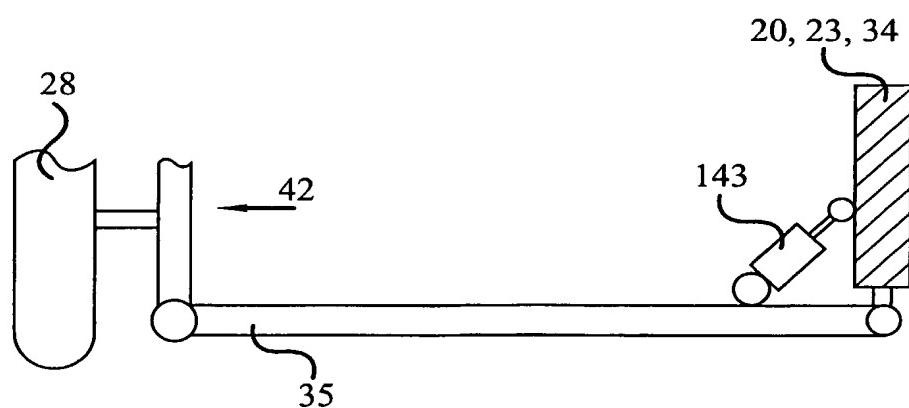


FIG. 4D

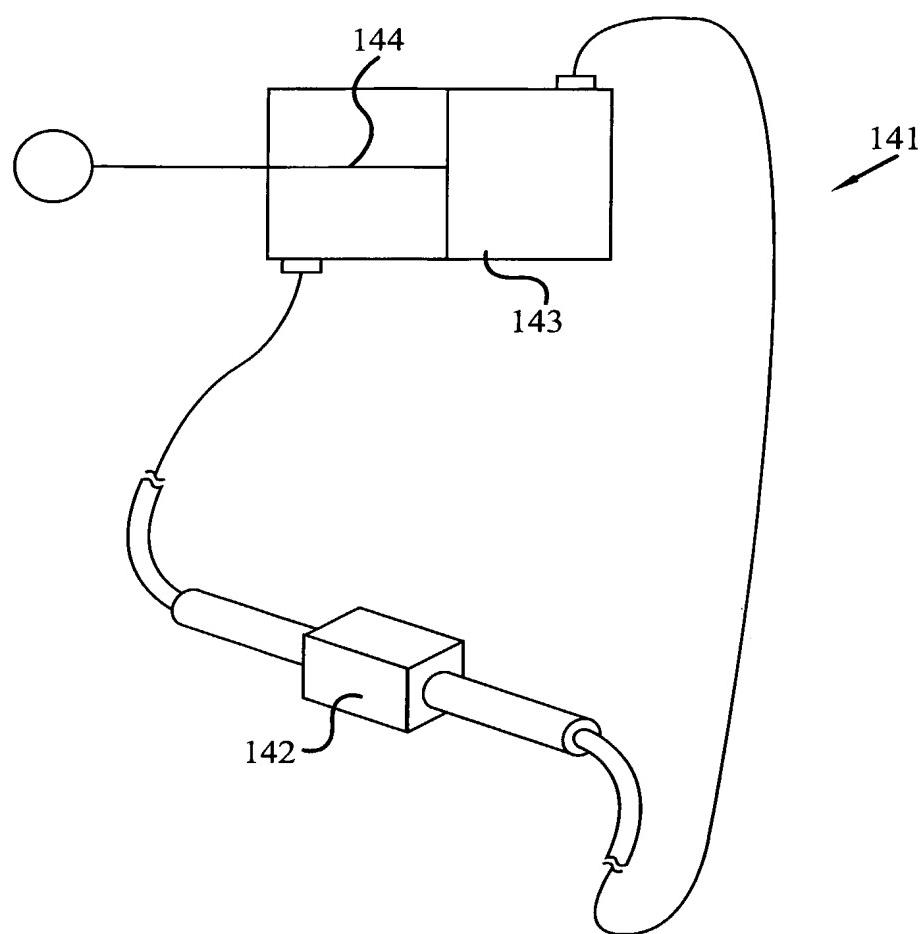


FIG. 4C

# INTERNATIONAL SEARCH REPORT

International application No.

PCT/US03/25267

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : B60G 17/01  
US CL : 280/5.52

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 280/5.52, 5.521, 5.522, 5.5, 5.504, 5.508, 5.509, 5.51, 5.512, 5.517, 5.518; 73/862.541

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
NONE

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4,826,206 A (IMMEGA) 02 May 1989 (02.05.1989), see column 17, line 47, column 18, line 16, column 22, lines 20-59.	72-73
---		-----
Y		71
X	US 4,546,997 A (SMYERS) 15 October 1985 (15.10.1985), see figures 3 and 4, column 18, lines 10-54, column 10, lines 40-54.	65-66 and 70
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Y		71,67,69
X	US 5,324,056 A (ORTON) 28 June 1994 (28.06.1994), see column 1 line 14.	1,21 and 41
Y	US 6,279,920 B1 (CHOUDHERY) 28 August 2001 (28.08.2001), see column 4, lines 58-67.	67 and 69
A	US 5,435,193 A (HALLIDAY) 25 July 1995 (25.07.1995), see entire document.	NONE

<input type="checkbox"/>	Further documents are listed in the continuation of Box C.	<input type="checkbox"/>	See patent family annex.
*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier application or patent published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search  26 March 2004 (26.03.2004)	Date of mailing of the international search report  <b>16 APR 2004</b>
Name and mailing address of the ISA/US  Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450 Alexandria, Virginia 22313-1450  Facsimile No. (703) 305-3230	Authorized Officer  Randolph Reese  Telephone No. (703) 308-1113